SEQUENTIAL
ELECTRONIC
SYSTEMS

ANALOG-TO-DIGITAL CONVERTERS

APPLICATIONS

- AEROSPACE
- AIRCRAFT
- SATELLITES AND MISSILES
- NUCLEONICS
- OCEANOGRAPHY
- MEDICAL ELECTRONICS
- DATA PROCESSING
- NAVIGATION EQUIPMENT

Series 100

FEATURES

- 6, 8, 10 and 12-bit conversions at a rate of up to 83,000 conversions per second!
- Ultra-high input impedance (50 megohms minimum) using FET op amp!
- Integrated circuit assemblies
- Printed circuit interconnections modular construction
- Miniature internal plug-in boards make converter readily expandable in bit capacity!
- Multifunction integrated circuits minimize space, weight, and power consumption!
- Built-in circuit for on-line operational check!
- Housed in small KB size MIL-T-27 can – can be mounted anywhere!
- Commercial and military units available!

SEQUENTIAL ELECTRONIC SYSTEMS, INC.
66 Saw Mill River Road, Elmsford, New York (914) LYric 2-8810 TWX 914 592 8368

DESCRIPTION

The Sequential A-to-D converters operate on a successive-approximation basis, using a high-speed voltage comparison method to determine the relative amplitude of an unknown d-c analog input signal (Vs) to a controlled-variable precision reference voltage (Vr). Figure 1 is a block diagram of the converter.

Once a "start conversion" command is received, a trial-and-error procedure is initiated during which Vr is varied in amplitude until it equals Vs (±½ quantum). At this time, the converter stops the comparison program and the resulting binary output is available for either serial or parallel extraction.

The reference voltage is varied in a binary fashion from 0 volts to ± full scale. For a bi-polar input signal, the first Vr is chosen to be 0 volts. If Vs< Vr, then Vr is switched to –½ full scale, and another comparison is made. If Vs is still less than Vr, then Vr is switched to –¾ full scale, and again a

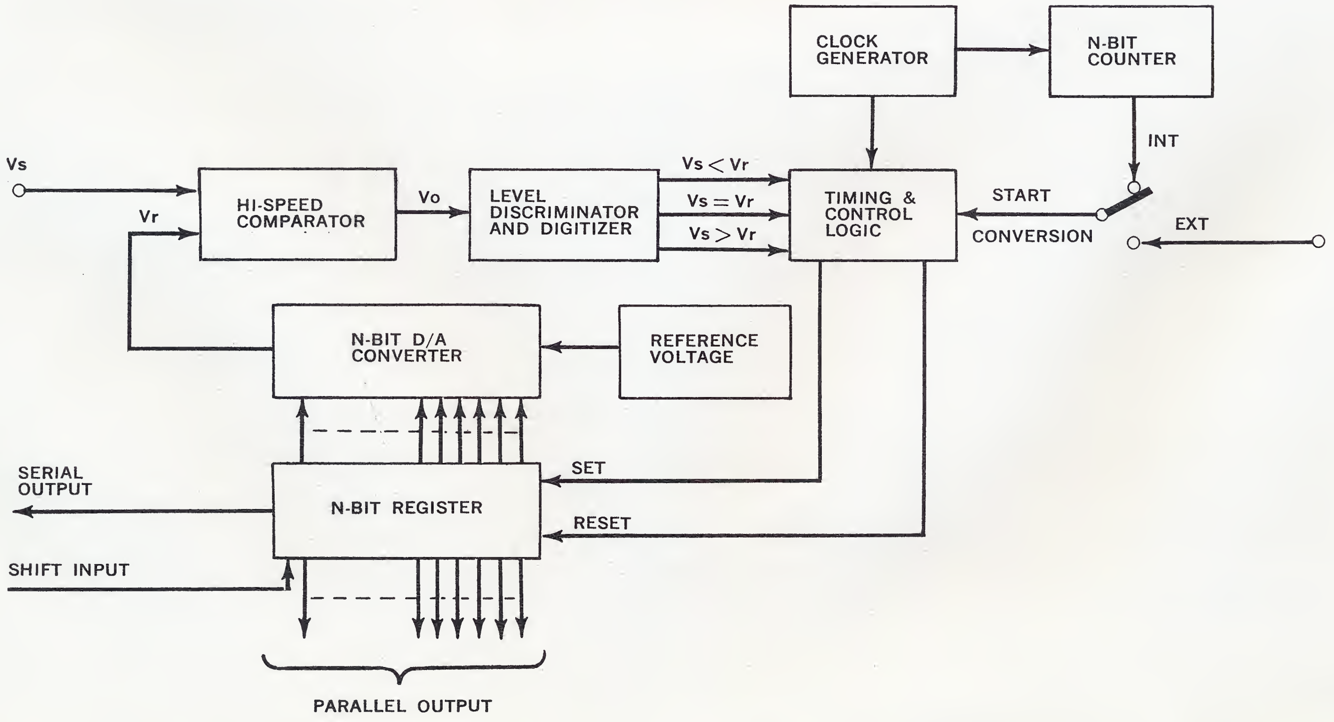

Figure 1 — Analog-to-Digital Converter, Block Diagram

comparison is made. If Vs had been greater than Vr, then Vr would be switched to −¼ full scale. Eventually, the logic will establish a value of Vr which agrees with Vs to within the resolution, or quantum, of the converter.

A conversion command can be applied to the converter either externally or internally. The switch for this selection is inside the module. In the "External Conversion" mode, a conversion cycle is initiated upon receipt of the positive-going transition occurring in the start conversion command.

In the "Internal Conversion" mode, an internal counter running from the converter clock determines the conversion frequency. There is a built-in delay between conversions which equals the time interval for serial extraction of data. This interval is determined by the customer's requirements and is programmed into the converter during final tests.

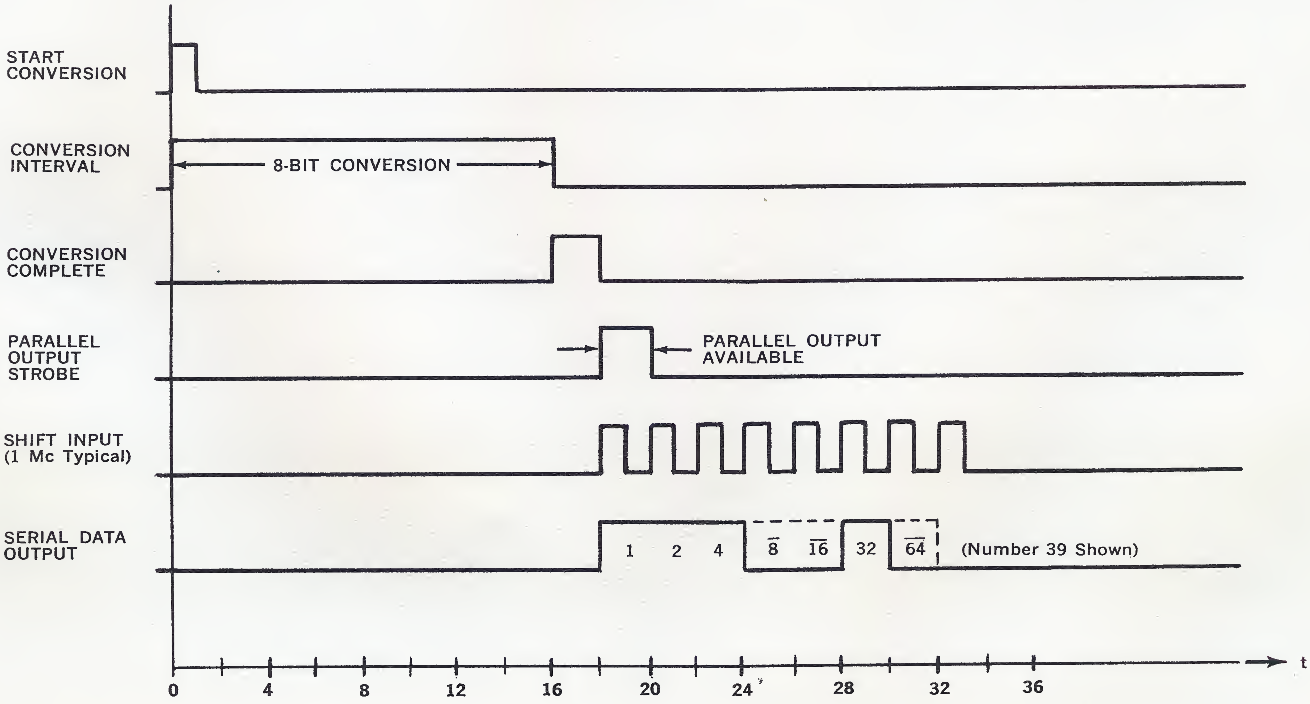

Figure 2 — Converter Timing Diagram (8-Bit Converter Shown)

ANALOG-TO-DIGITAL CONVERTERS Series 100

SES Model No.	Resolution (Bits)	Accuracy	Conversion Rate (Max)		Input Slew Rate
			convs/sec	usec/conv	(volts/sec)
N106AD	6	1%FS ±1/2LSB	83,000	12 usec	3300
N108AD	8	.4%FS ±1/2LSB	62,500	16 usec	830
N110AD	10	.1%FS ±1/2LSB	52,000	20 usec	200
N112AD	12	.03%FS ±1/2LSB	41,500	24 usec	50

Note: 6, 8, 10 bit models can be furnished with 12-bit accuracy

SPECIFICATIONS

Input Voltage Range: ±10 volts

Input Impedance: 50 megohms (minimum)

Input Format: (See Figure 2)

Start Conversion — 5.0 ±0.5V, 1.0 μsec pulse
2.0 ma sink capability

Shift Command — Group of N pulses at a maximum rep rate of 2×10^6 pulses/second and a minimum "on" width of 200 nsecs

Output Format: Serial or parallel

Serial
- (a) NRZ binary output
- (b) Maximum bit rate — 2×10^6 bits/second
- (c) Rise and Fall Times — less than 30 nsecs

Parallel
- (a) Maximum interrogate rate — 41,500 per second for 12-bit converter (See Table 1)
- (b) Output data delay from interrogation leading edge — less than 20 nsecs

Logic Levels:

Serial — Logic "1" — +5.0 ±0.5 volts, 50 ma drive capability
Logic "0" — 0.0 ±0.2 volts, 20 ma sink capability

Parallel — Logic "1" — +5.0 ±0.5 volts, 20 ma drive capability
Logic "0" — 0.0 ±0.2 volts, 10 ma sink capability

Timing: See Figure 2

Stability: Drift is less than 1/2 bit per month for temperature variation of ±10°C

Temperature Range: 0°C to 70°C for full accuracy

Weight: 2.5 pounds max

Size: See Figure 3

Input Power: +40 VDC ±2%, 200 ma, 1% regulation, ripple 20 mv p-p
−20 VDC ±2%, 10 ma, 1% regulation, ripple 20 mv p-p

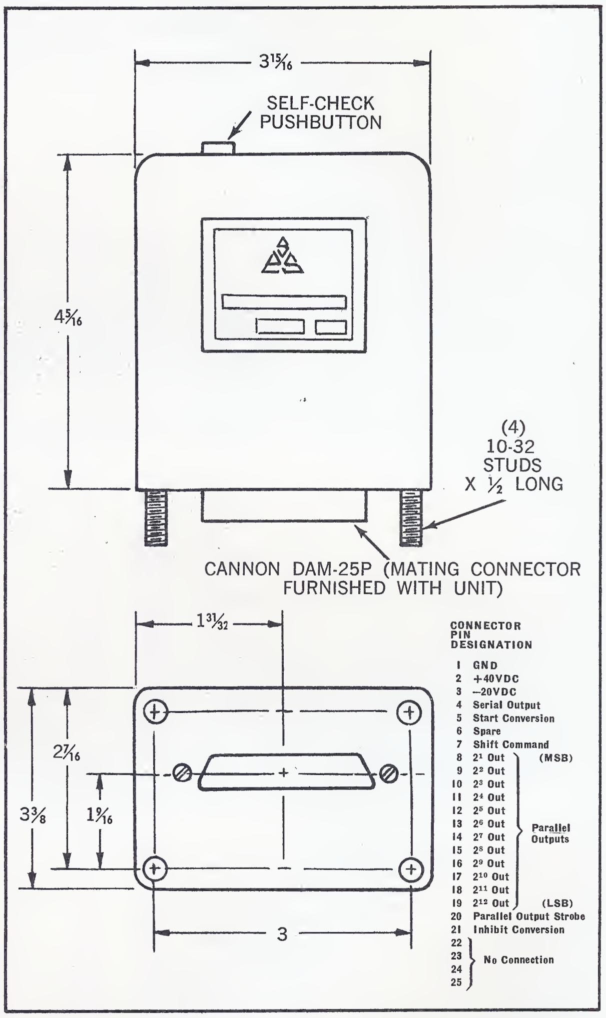

Figure 3 — Outline Dimensions

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ELECTROMECHANICAL
COMPONENTS & SYSTEMS DESIGN

THE SOURCEBOOK OF DESIGN IDEAS IN APPLIED ELECTROMECHANICS

JITTERLESS PHOTO RECON SYSTEMS

SEQUENTIAL ELECTRONIC SYSTEMS, INC.

66 Saw Mill River Road
Elmsford, New York

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JITTERLESS PHOTO RECON SYSTEMS

Eliminate the jitters without gearing or speed reducers

A problem of utmost concern confronting the military today is the ability to produce reconnaissance photos with sufficient detail to fully evaluate the terrain over enemy territory. The basic problem results from the inability to move film very slowly and accurately and smoothly. The "jitter" created by the drive as the film travels over the capstan, reduces the resolution to a point where much of the information being sought is lost.

Spiroid gears, metal to metal rollers and other similar speed reducers now in use have proven inadequate. M. Schiller, President, Sequential Electronics Systems, Inc. of Elmsford, New York has introduced two film drive systems that completely eliminate the necessity for gearing or speed reducers of any kind. The Sequential systems allow the operator to move film at any speed and maintain an instantaneous position accuracy of better than 1 arc second.

Sequential supplies airborne (explosion proof) and ground processing equipment that provides the ability to photograph terrain with a resolution which is greater than the present "state-of-the-art". In order to accomplish this end, two different systems are offered.

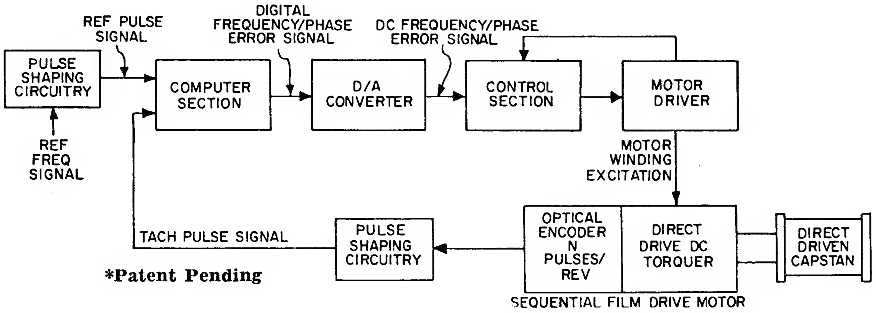
• *The basic* Sequential Film Drive System according to Mr. Schiller, consists of a Sequential Film Drive Motor and an FPL Control System. The motor incorporates a direct dc torquer and a capstan assembly which is an integral part of one end of the motor shaft. A high resolution optical encoder is integrally assembled to the other end of the shaft. The Frequency Phase Lock (FPL) Control System uses electronics to provide ultra precise speed and phase control of the motor shaft. Absolute speed synchronization is an inherent property of this system's mechanization, and can be achieved in the presence of drastic variations in supply voltage, load torque and environmental conditions.

• *The advanced* Sequential system is the Band-Scan FPL Control System which offers the ultimate in precision motor control. It retains all the advantages of the basic FPL System in terms of simplicity of implementation and sophistication of control, but in addition completely eliminates all inherently limiting characteristics (relating to control bandwidth and operational range) of sampled data phase locking systems that derive feedback information from a pulse-rate tachometer. Band Scan utilizes miniaturized Band-Scan FPL control electronics, a miniaturized Band-Scan Reference Generator, and an electro-optical modular Band-Scan Readout which integrally mounts to the control motor.

OPERATION OF THE BASIC FPL SEQUENTIAL FILM DRIVE SYSTEM

The angular speed and phase of the motor shaft are measured by a Sequential Optical Encoder, integrally mounted to the drive motor shaft, which produces N pulses per revolution. The tachometer contains a coded-disc, having a track with N opaque and N alternate clear segments, mounted to the motor shaft. The master discs are manufactured on an automatic circle dividing machine, developed by Sequential, which can produce coded-discs with a line accuracy of 0.33 seconds of arc. A light source is focused through a reticle, with the same line density as the coded-disc, onto the track of the disc. A photocell, mounted on the opposite side of the disc, senses the light as it passes through the track. The photocell output is amplified by an optical preamplified mounted in the tachometer housing. As the disc rotates, the light is alternately passed and blocked by the segments on the track. The output of the preamplifier is a sinusoidal signal that repeats N times per revolution. This output signal is passed to pulse shaping circuitry that produces a sharp tachometer pulse at each positive-going, zero cross-over of the sinusoidal signal. Thus, N tachometer pulses are produced for each revolution of the motor. At any speed, the tachometer pulse frequency, in pulses per second, is given by Ω N/60 where Ω is the motor speed in rpm.

A reference pulse train (Fig 1) is generated from a Reference Frequency Signal input whose frequency is exactly equal to the frequency that the tachometer signal would have when the motor is rotating at the correct speed. This reference signal and the tachometer signal are fed to the computer. The computer contains frequency-lock logic which compares the frequencies of these two signals and generates an error signal if there is a frequency difference. The magnitude and polarity



*Patent Pending

Fig 1 — Frequency Phase Lock (FPL) Control System.*

of this error signal is such, that when converted to dc, amplified and passed to the motor driver, the motor is forced to rotate at a speed at which the tachometer signal frequency exactly equals the reference frequency.

To maintain precise synchronization of the motor shaft, the computer section also contains phase-lock logic which compares the relative phase angle between the reference and tachometer signals, when frequency-lock has been achieved, and generates an error signal proportional to this phase angle. The phase error signal is used to control the motor excitation to maintain precise alignment between the tachometer and reference signals.

The unique feature of this basic control system, Mr. Schiller stated, is that the frequency-lock and phase lock logic circuits operate simultaneously, and the transition from the frequency control mode to the phase control mode performs automatically in a continuous manner, so that no switching signals or transients appear in the error signal.

The phase error information produced by the computer is in the form of relative pulse spacing between the reference and tachometer signals. The function of the D/A converter is to convert this relative pulse spacing information into a dc signal proportional to the phase error. This conversion is performed on a pulse-to-pulse basis, with no significant time constant and with virtually no ripple. The electrical bandwidth achieved is one-half the frequency of the reference signal, which permits design of an extremely wide-band and high gain control loop.

The Control Section contains stabilization circuitry which applies phase, velocity and acceleration control in the proper ratio, and with proper frequency characterisitcs, optimizes the closed loop performance of the control loop. This section also contains circuitry associated with the Motor Driver. The driver unit supplies the correct excitation to the motor windings to maintain constant shaft velocity. Excitation signals from the driver are fed to the Control Section, so that the driver and motor windings operate in a secondary, closed-loop manner. The effect of this type of operation is to linearize the torque output characteristic, and to virtually eliminate the electrical time constant of the motor windings.

If a torque disturbance is applied to the capstan, the phase angle between the tachometer and reference signals will shift, changing the phase error signal. The torque output of the motor will change by an amount which will just cancel the torque disturbance and maintain speed synchronization. In closed-loop operation, the maximum electrical phase shift is limited to $360/K_p$ degrees, where K_p is the electrical phase-lock gain. Since the tachometer produces N pulses per revolution, $360/K_p$ electrical degrees corresponds to $360/NK_p$ mechanical degrees. The mechanical phase locking that can be achieved is therefore a function of the tachometer pulse density (N), and the electrical phase-lock gain (K_p).

Values of K_p achievable with the proper dynamic stabilization are in the range of 20-40 db. These electrical gains coupled with the extremely high sensitivity of the optical tachometer determine open-loop gains on the order of 1,000,000 (120 db) radian/second/radian throughout the control bandwidth.

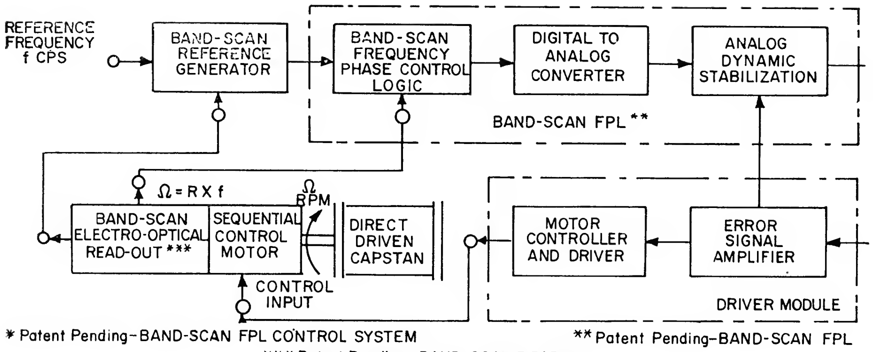
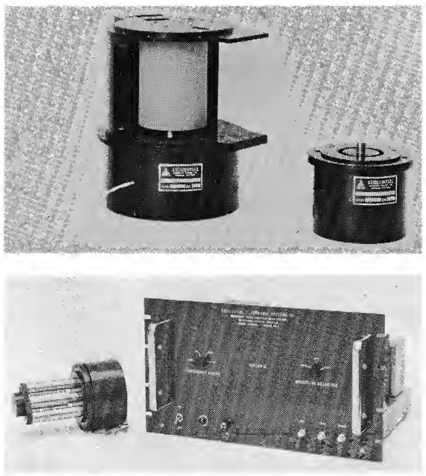


Fig 2 — Band-Scan FPL Control System.



Typical Film Drive Motors and Electronic Control Console for Sequential Film Drive System. Capstan, an integral part of the motor shaft, has total indicated runout less than 0.0001".

This gain produces closed-loop positional accuracies on the order of seconds of arc.

OPERATION OF THE BAND SCAN CONTROL SYSTEM

Added to all the features and capabilities of the basic FPL unit, the infinite resolution Band-Scan Readout (Fig 2), Mr Schiller said, has the rare capability of electro-optically monitoring continuous speed/phase coordinates and converting this information into the required digitized format at a constant conversion rate which is independent of shaft speed. It computes speed with zero error and position of phase with a maximum peak inaccuracy of 0.33 arc seconds, at a minimum settable conversion rate of 30 kc/s. This action produces a rate/position control system with the capability of constant closed-loop control bandwith of a minimum of 3kc/s (3db point) which functions from the zero speed through saturation speed of the control motor.

Position sensitivities are such that if the electronic gain were unity, 20 arc seconds of position error would correspond to a full applied torque command. Achievable electronic gains with the proper stabilizing elements are on the order of 40-60 db. This therefore produces total open-loop gains of 10,000,000 (140 db) radians/sec/radian throughout the control bandwidth; forcing an absolute closed-loop position control accuracy, independent of torque loading, of better than 0.5 arc seconds.

The practical aspects of such gain-bandwidth capabilities are that the effects of undesirable torque perturbations, arising either internal to the control motor, or externally applied by the load mechanism, are reduced by a minimum of 140 db within the spectral band of 0 to a minimum of

3 kc/s. This allows the utilization of standard dc commutating ball bearing torque motors for a degree of super-precision that up to now has been considered impossible to achieve. The Band-Scan FPL System can mechanize any type of ac or dc ball bearing or air bearing rotary drive. With this system the need for expensive precision air-bearings is almost entirely eliminated. A possible exception would come only in the most stringent mechanical requirements where drive shaft runout must be held to less than 25 micro-inches TIR.

Reference inputs to the Band-Scan Reference Generator are set by a pulse train whose frequency directly corresponds to commanded motor speed and whose phase relates to drive shaft position. The standard speed-frequency conversion rate is such that motor rpm is

$$\Omega = Rf$$

where f = reference frequency and
R = conversion ratio selected for a given application.

The reference generator samples and stores speed/phase command information. Updating of the coordinates in storage is once/cycle of the reference. The interrogation rate of the generator for information fed into the Band-Scan FPL is automatically made compatible with the conversion rate of the Band-Scan Readout.

For motor back-to-back speed/-phase control, the generator is not required and the Band-Scan Readout on the master motor functions as the command for the slave motor.

Natural binary coded or decimal rate and position information is directly available from the Band-Scan FPL for external readout on a counter.

The Sequential systems described are presently operational in both ground and airborne equipment for gathering, processing, transmitting and recording graphic information. Other applications include reconnaissance, facsimile, photo transmission, radar and infrared data recording, optical processors, and optical information recording. ■

Other SEQUENTIAL products include . . .

Camera Synchronization Systems
Film Drive Systems
Tape Drive Systems
Photo Reconnaissance Drive Systems
Magnetic Drum Synchronization Systems
Air Bearing Centrifuges
Rate/Position Control Systems
Facsimile Recorders & Scanner Drive Systems
Incremental Optical Shaft Angle Encoders
Whole Word Natural Binary Optical Encoders—Resolution to 2^{20}
Air Bearing Rate Tables
Air Bearing Gyro Test Tables
Optical Resolvers
Indexing Systems

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NEW ENGLAND R & D DIVISION

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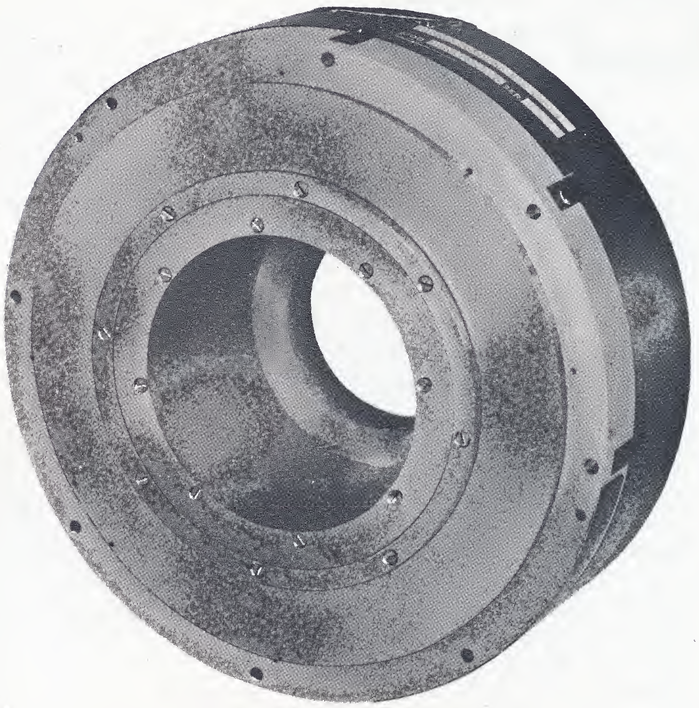
SEQUENTIAL ELECTRONIC SYSTEMS

19 BIT NATURAL BINARY OPTICAL ENCODER

FEATURES

- 19 Bit resolution in 8 inch diameter housing
- All electronics self-contained in encoder housing
- Integrated circuit assemblies
- Printed circuit interconnections
- Modular construction
- Plug-in lamp assemblies, field replaceable
- Fiber optic disc illumination
- Unique locked-beam optical readout
- No trim adjustments
- Outputs unaffected by power supply variations and bulb aging
- One hour in-field MTTR
- Projected MTBF 15,000 Hours
- Meets all applicable MIL-Specs.



APPLICATIONS

• Star Trackers • Antennas
• Theodolites • Control Systems • Gimbal Systems
• Numerically Controlled Machine Tools • Inertial Platforms

SERIES 80NB

DESCRIPTION

The Sequential Natural Binary optical shaft angle encoder generates digital word representations of absolute angular rotations. The representation is directly obtained and presented in a natural binary format that can be continuously displayed, or interrogated on command by low-level electrical pulses.

All electro-optical assemblies and required electronic readouts, including output registers and interrogation circuitry, are wholly contained within the encoder housing. Electronic assemblies contain conservatively rated components and are fabricated with integrated microcircuits and packaged into functional modules. Modules are interconnected on printed circuit boards.

Reference light beams are d.c. excited and transmitted to proper readout stations via incoherent fiber optic bundles. The d.c. excitation enables a time-continuous digital readout. For maximum flexibility, and for operation with systems requiring interrogated outputs, associated integrated low-level logic circuitry and registers are included.

The encoder utilizes a precision natural binary optical disc manufactured by Sequential on its specially designed electrically-programmed automatic circle dividing machine. Bit accuracies on each track have been calibrated to a peak maximum position error of 0.33 arc-seconds from any bit to any other arbitrary bit. Each track is synchronized to any other track with bit leading and trailing edges aligned to within a maximum inaccuracy of 0.5 arc-seconds.

A proprietary (patent pending) optical locked-beam technique is utilized in the readout of the fine tracks. The locked-beam enables outputs to maintain "set-in" phase relationships, independent of shaft position or direction of rotation. It also insures that the average d.c. level, about which any signal varies, is maintained at zero volts for wide variations in both lamp and system power supplies. The reliability of these zero levels directly reflect into the analog-to-digital conversion accuracy and represents a very significant improvement over the prior "state-of-the-art" in optical encoders.

All reading stations on the fine tracks are differentially read out, and the locked-beam provides an identical optical path from the bulb excitation filament to each silicon cell pickoff. Since the optical paths are the same for each station in a differential pair, relatively gross movements, resulting from either bulb replacement or variations in filament "hot-spot" due to bulb aging, will have no effect on the zero level or relative phasing from one readout station to any other, and will manifest itself

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only in changes of signal amplitude. This encoder series offers a unit in which aging or spatial orientation of the filament does not effect encoder performance. This advantage is further emphasized by the very significant increase in MTBF figure, related to catastrophic bulb failure only, over encoders in which filament aging effects must be considered. Encoders that exhibit critical dependence on filament position inherently do not have the capability of expeditious bulb replacement in the field, and require elaborate trimming procedures.

Physical limitations of ball-bearing assemblies, (sub-harmonics, runout, higher harmonic effects, and random errors) coupled with a small diameter encoder housing, places an upper limit on the number of tracks that can be directly viewed by the electro-optical system. This upper limit corresponds to a highest track density where digital bits read out at any one station, are aligned to within a total tolerance of one-half bit with respect to the digital bits readout at any other station on the same track. A unique Sequential optical phasing array, which acts in combination with mechanical phasing of the readout stations on the densest track, directly generates multi-phased electro-optical outputs with all point symmetric harmonic errors reduced to a level below 0.5 arc-seconds peak. The electrical signals corresponding to the optical outputs are phased such that phase displacements between signals correspond to the required resolution of the encoder. These signals are processed by digital vernier logic to precisely generate the remaining higher density bits.

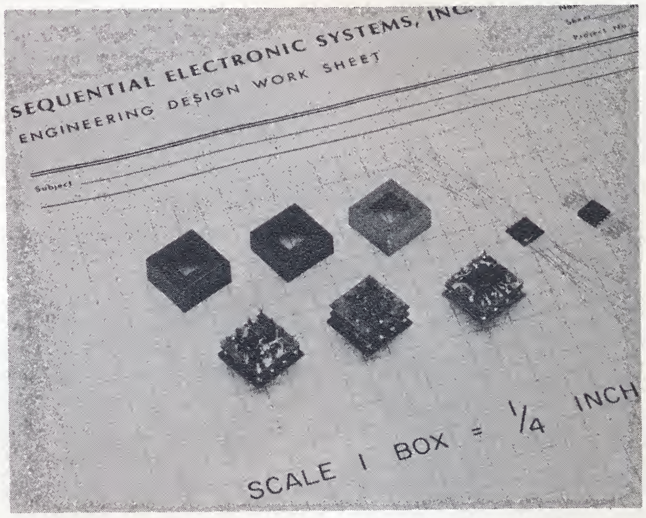
The digital vernier functions on the opto-mechanical level as differentiated from encoders which attempt to accomplish the same end by processing electrical outputs utilizing amplitude scaling and associated summations. Error analysis of the latter technique graphically illustrates the critical dependence of encoder accuracy on the stability of signal amplitudes with time, temperature, and spatial orientation (amplitude modulation of waveforms due to harmonic error cancellation). The Sequential digital vernier technique, due to its locked-beam optomechanical approach, is not dependent upon signal amplitude stability, and can tolerate wide variations in amplitude due to variations in light source intensity.

Serial U-scan logic is incorporated to prevent ambiguous readings. This logic inhibits transitions of all coarse tracks until the fine track transitions have occurred. Through this technique, all transitions are synchronized to the transitions occurring on the densest track. Total carry time delay in the serial logic is less than 4 micro-seconds. An internally generated "inhibit pulse", which is gated by transitions on the densest track, functions to prevent output changes until termination of the total carry time delay.

The accuracy of an encoding system compatible with a resolution of nineteen bits is available in a standard unit with a diameter of 8.0 inches and a depth of 2-13/16 inches. Units are available in either hollow-shaft or solid-shaft configurations. The standard hollow-shaft unit has a thru hole whose diameter is 2-7/16 inches. All Sequential encoders are designed to meet applicable MIL-specs.

HYBRID-MICROCIRCUIT FUNCTIONAL MODULES

There are three different types of microcircuit functional modules in the encoder readout amplifiers, buffer amplifiers and level detectors. Although several different circuit operations are required in the encoder, these are performed with only three basic modules, to reduce the number of module types used. All components are assembled on miniature printed circuit boards with soldering used to facilitate easy repair of these units. Each module has a 12 pin header which plugs into a printed circuit board. This printed circuit board interconnects all modules and eliminates costly wiring operations while increasing overall system reliability. All circuits are conservatively designed and power consumption is minimal.

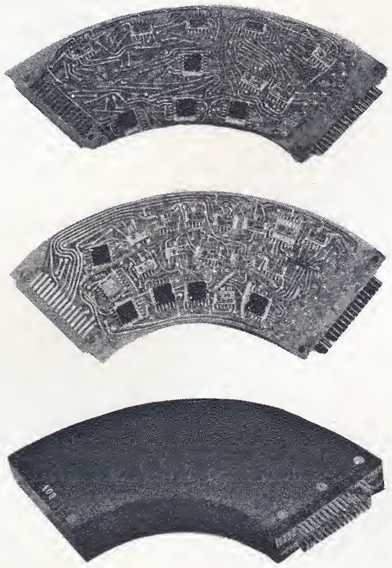


ANALOG SIGNAL CONDITIONING ASSEMBLY

The plug-in signal conditioning assembly consists of hybrid-microcircuit buffer amplifier and level detector modules, interconnected on a printed circuit board. These modules shape the electrical output signals from the readout amplifiers to provide proper input signals to the digital logic. The readout amplifiers are located on the optics plate and monitor the high density tracks. In addition, the signal conditioning assembly directly monitors the outputs from the photosensors associated with the coarser tracks. Any module can easily be replaced in the field.

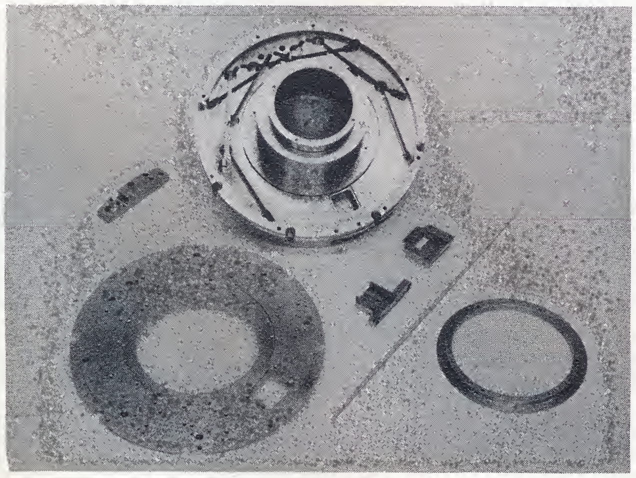
DIGITAL LOGIC ASSEMBLY

This assembly contains the U-scan logic, the vernier interpolation logic, the interrogation and inhibit logic, the output storage registers which hold the outputs between interrogations, and the output line drivers. The U-scan logic prevents ambiguous readings by synchronizing the transitions on each track to the fine-track transitions. The verniered outputs are digitally formed from the fine track readout signals. All interconnections are made on two printed circuit boards which are designed for field replacement of any sub-module. This assembly is built completely with integrated microcircuits, conservatively designed and having minimal power dissipation.



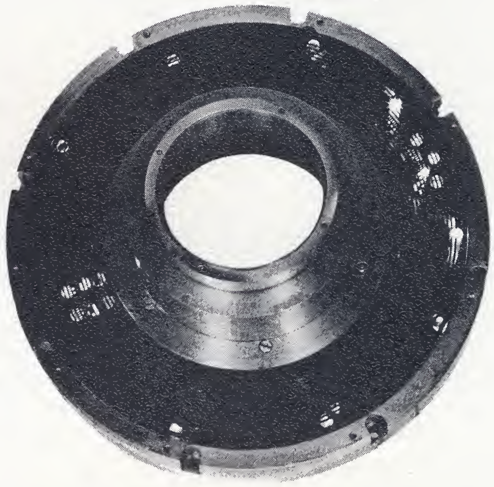
MECHANICAL ASSEMBLIES

Major mechanical assemblies for the encoder are illustrated. All parts are fabricated from stainless steel for structural rigidity and stability at all metal-glass interfaces.



ILLUMINATED OPTICAL DISC

All tracks on the disc are illuminated by two plug-in lamp assemblies. Fiber optics and associated lens assemblies transmit the light from the lamp assemblies to the appropriate reading stations.



CODED DISC

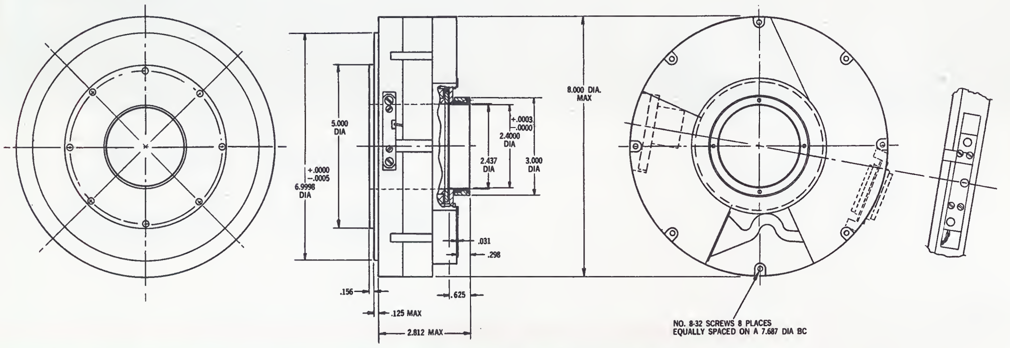
The coded disc consists of sixteen natural binary tracks. This optical disc was manufactured by Sequential on its unique electrically-programmed automatic circle dividing machine. Bit accuracies on each track have been calibrated to a peak maximum position error of 0.33 arc-seconds from any bit to any other arbitrary bit. All tracks are synchronized for bit transitions to within a maximum error of 0.5 arc-seconds.

COUPLINGS

In order to preserve the inherent high accuracy of the Sequential encoder, precision flexible couplings are required for mounting. Sequential has available flexible couplings specifically designed to hold wind-up and misalignment errors to negligible levels. These couplings are available as accessories.

SEQUENTIAL 19 BIT NATURAL BINARY OPTICAL SHAFT POSITION ENCODER

SERIES 80NB



SPECIFICATIONS

QUANTA/REVOLUTION	2^{19}
RESOLUTION	2.47 arc seconds
ACCURACY INCLUDING QUANTIZING-STANDARD DEVIATION	±1.1 arc seconds
ACCURACY INCLUDING QUANTIZING-PEAK DEVIATION	±2.47 arc seconds
ANGULAR ROTATION (1)	Continuous
ANGULAR VELOCITY FOR FULL ACCURACY	100 deg/sec
MAXIMUM SLEWING VELOCITY (OPERATING)	300 deg/sec
MAXIMUM SLEWING VELOCITY (NON OPERATING)	200 rpm
ANGULAR ACCELERATION FOR FULL ACCURACY	100 deg/sec^2
MAXIMUM READOUT DELAY – CARRY TIME PLUS INHIBIT TIME	4 microseconds
MAXIMUM INTERROGATION RATE	100 kc (Standard)
OUTPUT SIGNAL LEVEL	
LOGIC "1" (VOLTS POSITIVE)	4 ±1 volt into 2000 ohm load (2)
LOGIC "0" (VOLTS POSITIVE)	0.2 volts max. (2)
OUTPUT FORMAT	Parallel, 19 lines (3)
OUTPUT DISPLAY TIME (AFTER INTERROGATION)	Gated or continuous to suit customer requirements (4)
INTERROGATION PULSE INPUT	+6 volts into 120 ohms
BREAKAWAY TORQUE	5 oz – in
TEMPERATURE; OPERATING	–20°C to 65°C
TEMPERATURE; NON-OPERATING	–50°C to 100°C
HUMIDITY	95% max.
INPUT POWER (5)	
VOLTAGE	$+5\,(^{+0.0}_{-0.5})$ vdc +12 (±0.2) vdc –6 (±0.2) vdc
CURRENT	
+5 VDC	2.0 amps, max
+12 VDC	0.35 amps, max
–6 VDC	0.35 amps, max
REGULATION	±3%
RIPPLE	0.1%

NOTES

1. Both solid and hollow shaft units are available.
2. Other logic levels are available.
3. Conversion to a serial format by an auxiliary package, or a direct serial output format from the encoder's Digital Logic Assembly is available.
4. Auxiliary displays are available.
5. Auxiliary power supplies are available.

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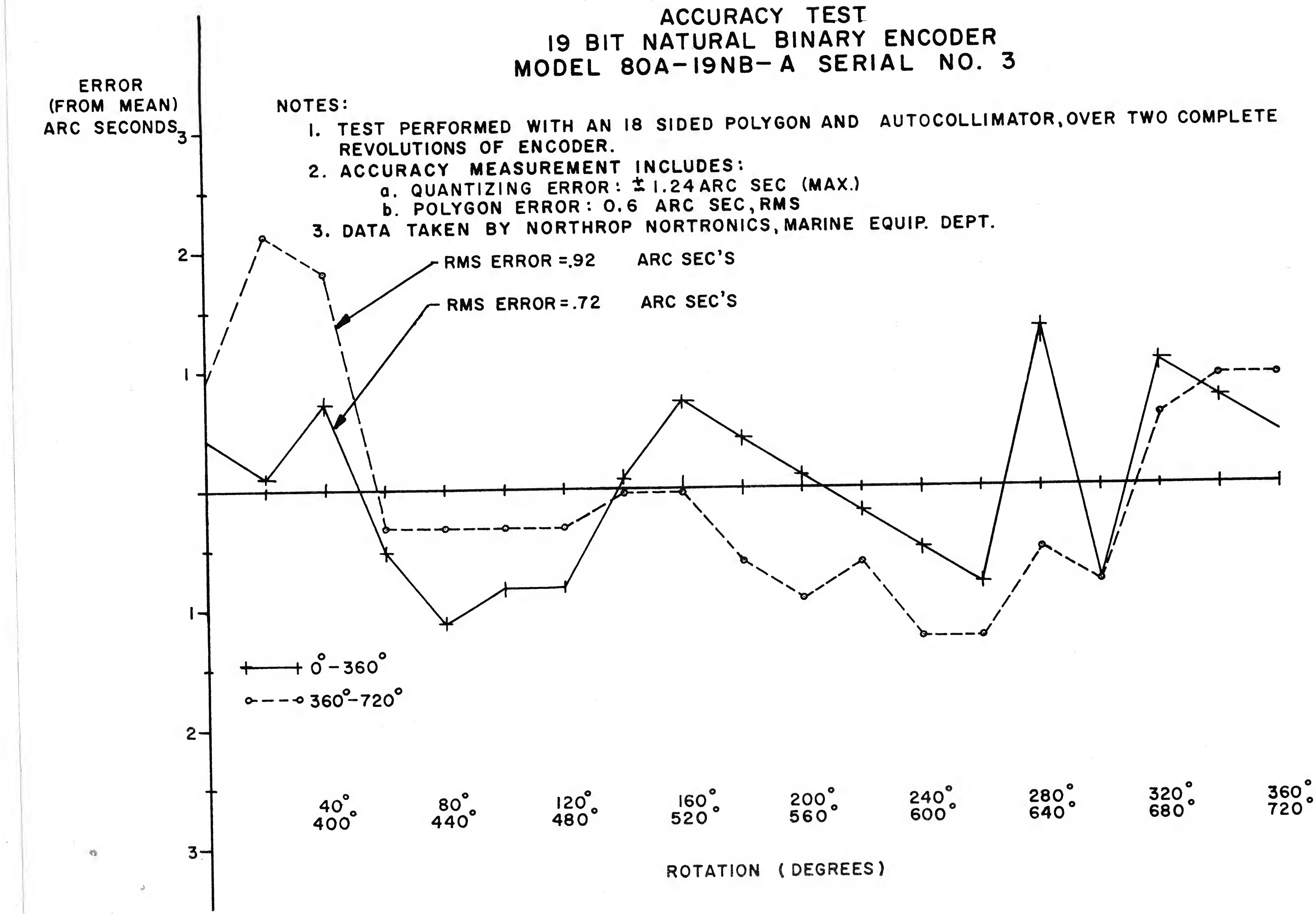
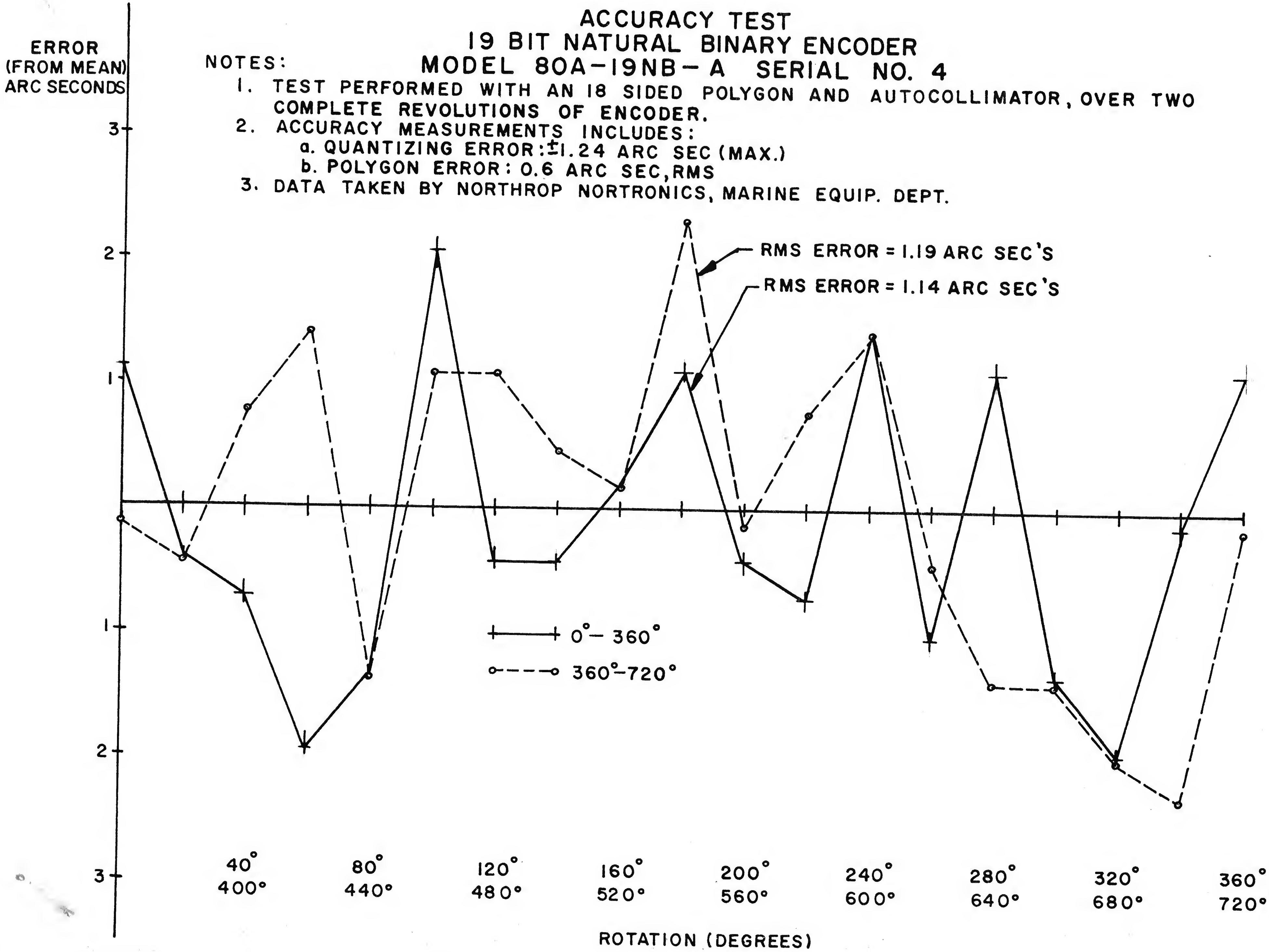
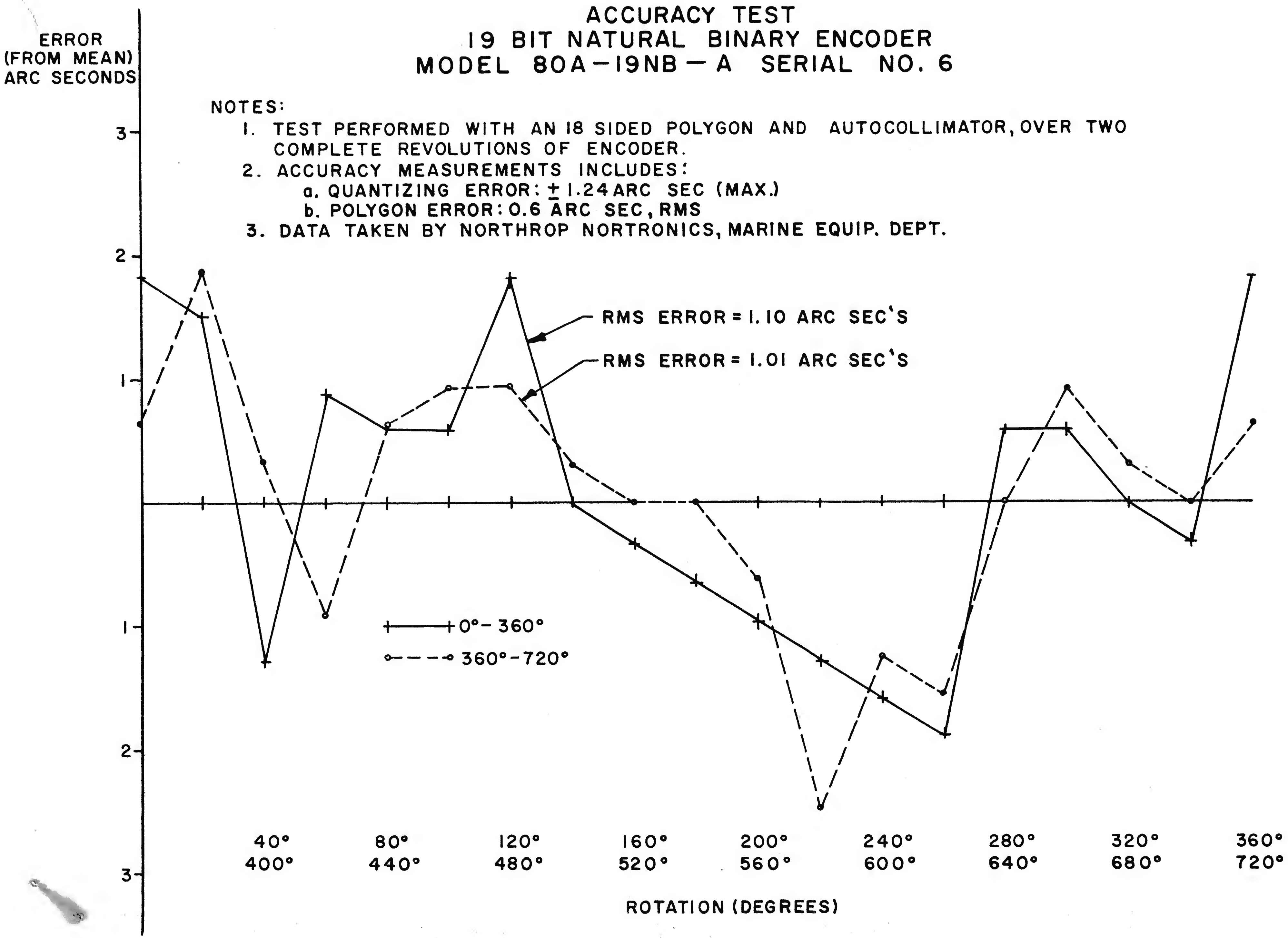


ACCURACY TEST
19 BIT NATURAL BINARY ENCODER
MODEL 80A-19NB-A SERIAL NO. 3
ERROR (FROM MEAN) ARC SECONDS
NOTES:
1. TEST PERFORMED WITH AN 18 SIDED POLYGON AND AUTOCOLLIMATOR, OVER TWO COMPLETE REVOLUTIONS OF ENCODER.
2. ACCURACY MEASUREMENT INCLUDES:
a. QUANTIZING ERROR: ± 1.24 ARC SEC (MAX.)
b. POLYGON ERROR: 0.6 ARC SEC, RMS
3. DATA TAKEN BY NORTHROP NORTRONICS, MARINE EQUIP. DEPT.
RMS ERROR = .92 ARC SEC'S
RMS ERROR = .72 ARC SEC'S
3
2
1
1
2
3
0°-360°
360°-720°
40° 400°
80° 440°
120° 480°
160° 520°
200° 560°
240° 600°
280° 640°
320° 680°
360° 720°
ROTATION (DEGREES)


ACCURACY TEST
19 BIT NATURAL BINARY ENCODER
MODEL 80A-19NB-A SERIAL NO. 4
NOTES:
1. TEST PERFORMED WITH AN 18 SIDED POLYGON AND AUTOCOLLIMATOR, OVER TWO COMPLETE REVOLUTIONS OF ENCODER.
2. ACCURACY MEASUREMENTS INCLUDES:
a. QUANTIZING ERROR: ±1.24 ARC SEC (MAX.)
b. POLYGON ERROR: 0.6 ARC SEC, RMS
3. DATA TAKEN BY NORTHROP NORTRONICS, MARINE EQUIP. DEPT.
ERROR (FROM MEAN) ARC SECONDS
3
2
1
1
2
3
RMS ERROR = 1.19 ARC SEC'S
RMS ERROR = 1.14 ARC SEC'S
0° – 360°
360° – 720°
40° 400°
80° 440°
120° 480°
160° 520°
200° 560°
240° 600°
280° 640°
320° 680°
360° 720°
ROTATION (DEGREES)

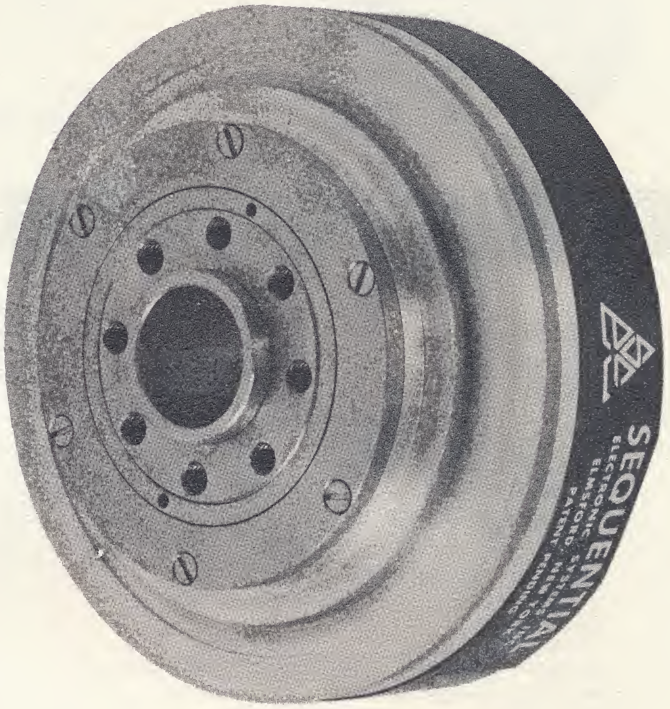


ACCURACY TEST
19 BIT NATURAL BINARY ENCODER
MODEL 80A-19NB-A SERIAL NO. 6
ERROR (FROM MEAN) ARC SECONDS
NOTES:
1. TEST PERFORMED WITH AN 18 SIDED POLYGON AND AUTOCOLLIMATOR, OVER TWO COMPLETE REVOLUTIONS OF ENCODER.
2. ACCURACY MEASUREMENTS INCLUDES:
a. QUANTIZING ERROR: ± 1.24 ARC SEC (MAX.)
b. POLYGON ERROR: 0.6 ARC SEC, RMS
3. DATA TAKEN BY NORTHROP NORTRONICS, MARINE EQUIP. DEPT.
RMS ERROR = 1.10 ARC SEC'S
RMS ERROR = 1.01 ARC SEC'S
0°-360°
360°-720°
3
2
1
1
2
3
40° 400°
80° 440°
120° 480°
160° 520°
200° 560°
240° 600°
280° 640°
320° 680°
360° 720°
ROTATION (DEGREES)

SEQUENTIAL ELECTRONIC SYSTEMS

OPTI-SCAN

INCREMENTAL OPTICAL ENCODER



FEATURES

- Resolution to 2^{16} in 3½ inch diameter housing
- Signal-to-noise ratio greater than 26 db
- Operating temperature range from —55°C to +71°C
- Sine-cosine outputs available for multi-speed resolver servo applications
- All electronics self-contained in encoder housing
- Integrated circuit assemblies
- Printed circuit interconnections
- Modular construction
- Unique locked-beam optical readout
- Plug-in lamp module, field replaceable
- Fiber optic disc illumination
- No trim adjustments
- In-field repair capability
- Outputs unaffected by power supply variations and bulb aging
- 3 year lamp life
- Projected electronics MTBF — 6 years
- Meets all applicable MIL-Specs

SERIES 35I

DESCRIPTION

Sequential OPTI-SCAN "pancake" incremental encoders are uniquely designed for gimbal frame mounting. The encoder bearing, by supporting the gimbal shaft, functions as the gimbal pivot. By including the readout electronics and level detectors entirely within the encoder housing, additional space is saved and greater design flexibility provided.

OPERATION

The code track inscribed on the integral optical disc has a maximum density of 2^{14} (16,384) clear and opaque radial sectors. On special orders requiring limited operating temperature ranges, the maximum resolution increases to 2^{16} (65,536) clear and opaque radial sectors. A second track on the disc provides a once per revolution index mark. This index mark is precisely synchronized to maintain a fixed spatial relationship with the high density track.

A single 5 volt incandescent lamp is used. Reference light beams are d.c. excited and transmitted to the readout stations via incoherent fiber optic bundles.

The OPTI-SCAN optical readout (patent pending) employs a locked beam technique to generate the quadrature-phased sine-cosine outputs. The locked-beam approach insures that these outputs exactly maintain their phase relationship independent of shaft position and gives an output signal-to-noise ratio greater than 26db. It also insures that the average dc output level, about which the signal varies, is maintained at zero for wide variations in both the lamp and amplifier power supplies. This feature guarantees constant duty cycle at the level detector outputs. The locked beam also extends the useful life of the encoder and permits in-field replacement of the plug-in lamp module without requirement for trim adjustments.

A pair of silicon photocells, connected back-to-back, are utilized in each channel (sine, minus sine, cosine, minus cosine) to generate the sinusoidal output signals. These signals vary about a *true zero dc voltage level*. For example, with a 2^{14} primary disc, discrimination of the two null crossings per cycle of the signal from each of the two quadrature channels provides angular resolution of 2^{16} (65,536) increments per shaft revolution with a minimum accuracy of ± one count at all shaft positions. The readout electronics associated with each output channel and the zero index channel are wholly contained within the encoder package. This includes the electronics which generate the sinusoidal output and the zero index signal, and the level detectors that generate the output dc levels (square wave). All electronics in the encoder housing are integrated circuit assemblies.

APPLICATIONS

OPTI-SCAN "pancake" encoders are presently field operational. The electronic circuits employed were developed for the military and use severely derated components assuring long MTBF. The projected MTBF of the electronics is 6 years. Lamps are derated to give a minimum rated life of 3 years.

An optical signal generator similar to that used for generating the sine-cosine outputs is provided for applications requiring the zero reference. This signal generator provides an accuracy and stability of the zero reference crossover equal to those of the count channels. By incorporating this technique a once per revolution signal is formed at a fixed shaft position and this fixed position corresponds to any desired position within one cycle of the sine-cosine count channels. The amount of hysteresis required in the count channels and the zero reference channel can be varied depending upon the application.

OPTI-SCAN encoders replace the commonly used synchro generators providing simple and direct analog-to-digital conversion. The encoder requires only elementary logic to form the clockwise and counterclockwise pulses. These pulses may be used as inputs to a computer or counter to provide shaft position data in digital form. Separate packages are available for the electronics required to convert the level detector outputs to two line count information, and the zero reference output to a narrow pulse.

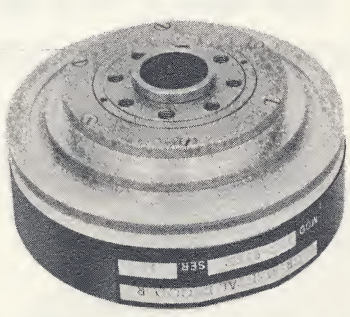
OTHER ENCODERS

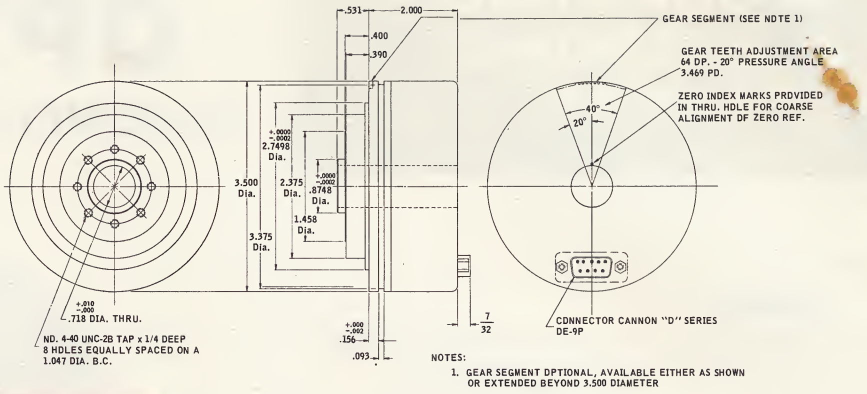
For higher resolution requirements, Sequential supplies incremental encoders up to 2^{20}. These encoders employ a larger disc and are larger in diameter.

Sequential also produces a line of direct reading, photo-optical encoders which produce electrical pulse outputs in parallel, cyclic binary, natural binary or other codes corresponding to angular shaft position.

SEQUENTIAL ELECTRONIC SYSTEMS, INC.
66 Saw Mill River Road, Elmsford, New York (914) LYric 2-8810 TWX 914 592 8368

OPTI-SCAN SERIES 35I INCREMENTAL OPTICAL ENCODER





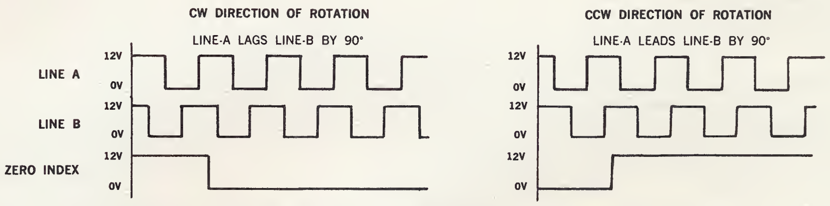
SPECIFICATIONS

Resolution (1)	Up to 65,536 zero crossings/ shaft rev.
Optical Disc Accuracy	0.2 Arc seconds from one line to any other arbitrary line around a revolution
Output Signal Accuracy (2) (maximum error between any two zero crossings)	±½ bit
Output Signals (Sine-cosine channels and zero index) (3)	
Amplitude	12 ±2 volts
Rise and Fall Time (10% to 90% points)	0.2 microseconds
Polarity (4)	positive
No Signal output	±0.2 volts
Output Impedance	less than 4000 ohms
Output Signal-to-Noise Ratio	26 db min.
Input Power	
Lamp Power	
Voltage	5 ±0.25 vdc
Current	225 ma
Regulation	±3%
Ripple	0.1%
Polarity	positive or negative
Amplifier Power	
Voltage	plus and minus 12 ±1 vdc
Current	
+12 vdc	65 ma
−12 vdc	65 ma
Regulation	±3%
Ripple	0.1%

Maximum starting torque (over operating temperature range)	4.0 in-oz
Maximum recommended mechanical load (Applied at end of shaft) (5)	
Axial	75 lbs.
Radial	75 lbs.
Weight	3 lbs.
Maximum Bit Rate for Full Accuracy (6)	30,000 cps
Maximum non-operating (slewing) speed	3000 rpm
Temperature Range	
Operating	−55°C to +71°C
Non operating	−65°C to +85°C
Humidity	97%
Altitude	50,000 feet
Vibration	
Operating	1.5g @ 10 to 55 cps, per MIL-E-5272C, Procedure XI
Non-Operating	10g @ 5 to 55cps per MIL-E-5272C, Procedure XI
Shock (non-Operating)	Will withstand 9 shocks of 30g, each 11 ±1 millisecond duration
Life	
Bearings (minimum 3000 rpm)	2 x 10^8 revolutions
Lamp (minimum rated)	3 years
Amplifiers (projected MTBF)	6 years

Notes:

1. Resolution to 2^{18} in 3½ inch housing available for operation over limited temperature range
2. The output signal accuracy does not include the quantizing error of ±½ bit
3. Count channel electronics to convert the analog signals to CW and CCW pulses which may be used as inputs to a computer or counter are available in an external package. This external package also processes the zero index signal, providing a narrow output pulse
4. Negative polarity outputs are available
5. Both solid and hollow shaft units are available
6. Higher bit rates available



Direction of rotation as viewed from mounting flange end

OUTPUT SIGNALS

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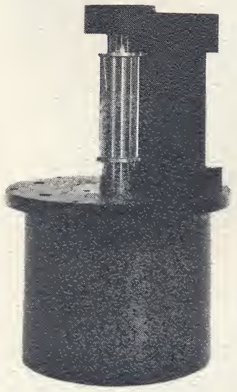
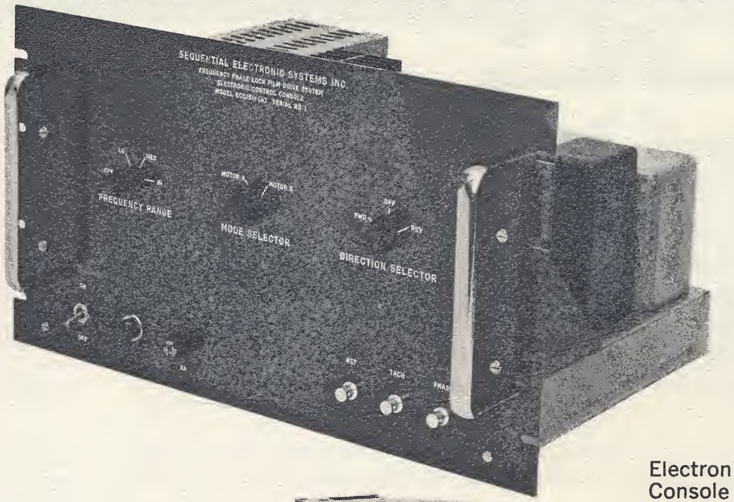
SEQUENTIAL ELECTRONIC SYSTEMS

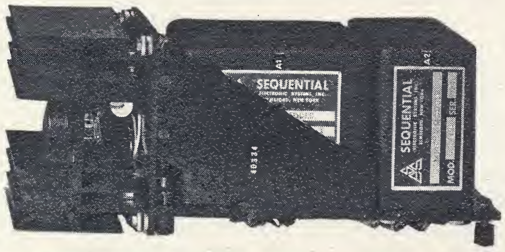
FILM DRIVE SYSTEMS



Film Drive Motor with integral BAND-SCAN Readout System



Electronic Control Console for FPL Film Drive System with typical drive motors.



Electronic module rack for BAND-SCAN Film Drive System.

FEATURES

- DIRECT DRIVE INTEGRAL CAPSTAN
- ABSOLUTE SPEED SYNCHRONIZATION
- 1 ARC-SECOND POSITIONAL ACCURACY — ZERO CUMULATIVE ERROR
- 3KC CLOSED LOOP CONTROL BANDWIDTH
- 7 FOOT-POUND TORQUE CAPABILITY
- MEETS ALL APPLICABLE MIL-SPECS
- 140db CLOSED-LOOP FLUTTER REDUCTION
- INTEGRAL ELECTRO-OPTICAL TRANSDUCER
- MINIATURIZED MODULAR ELECTRONICS
- 100 MICRO-INCH MAX. CAPSTAN RUNOUT
- TRUE ZERO-SPEED TO SATURATION SPEED CAPABILITY
- ULTRA-PRECISE MECHANICAL ASSEMBLIES

APPLICATIONS

These Film Drive Systems are presently operational in both ground and airborne equipment for gathering, processing, transmitting and recording graphic information. Their fields of application include reconnaissance, facsimile, photo transmission, radar and infra-red data recording, optical processors, and optical information recording.

These systems can provide absolute capstan speed setting to any desired value, synchronization of the capstan speed and phase to an external reference, or speed/phase synchronization of any number of drives, either local or remote, to a master drive system or external reference. They can also be implemented to provide either continuous film motion with the absolute film position controlled to seconds of arc, or incremental positioning to this accuracy.

SEQUENTIAL ELECTRONIC SYSTEMS, INC.
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SEQUENTIAL ELE

FREQUENCY PHASE LOCK CONTROL SYSTEM* The Frequency Phase Lock (FPL) Control System* provides ultra precise speed and phase control of the motor shaft. Absolute speed synchronization is an inherent property of this system mechanization, and short term phase perturbations of less than one part per million can be achieved in the presence of drastic variations in supply voltage, load torque and environmental conditions.

The Sequential (FPL) Film Drive System consists of a Sequential Film Drive Motor and an FPL Control System. The motor incorporates a direct drive DC torquer, and a capstan assembly which is an integral part of one end of the motor shaft. A high resolution optical encoder is integrally assembled to the other end of the shaft.

OPERATION The angular speed and phase of the motor shaft are measured by a Sequential Optical Encoder, integrally mounted to the drive motor shaft, which produces N pulses per revolution. The tachometer contains a coded-disc, having a track with N opaque and N alternate clear segments, mounted to the motor shaft. The master discs are manufactured on an automatic circle dividing machine, developed by Sequential, which can produce coded-discs with a line accuracy of 0.33 seconds of arc. A light source is focused through a reticle, with the same line density as the coded-disc, onto the track of the disc. A photocell, mounted on the opposite side of the disc, senses the light as it passes through the track. The photocell output is amplified by an optical preamplifier mounted in the tachometer housing. As the disc rotates, the light is alternately passed and blocked by the segments on the track. The output of the preamplifier is a sinusoidal signal that repeats N times per revolution. This output signal is passed to pulse shaping circuitry that produces a sharp tachometer pulse at each positive-going, zero cross-over of the sinusoidal signal. Thus, N tachometer pulses are produced for each revolution of the motor. At any speed, the tachometer pulse frequency, in pulses per second, is given by $\Omega N/60$, where Ω is the motor speed in RPM.

A reference pulse train is generated from a Reference Frequency Signal input whose frequency is exactly equal to the frequency that the tachometer signal would have when the motor is rotating at the correct speed. This reference signal and the tachometer signal are fed to the computer. The computer contains frequency-lock logic which compares the frequencies of these two signals, and generates an error signal if there is a frequency difference. The magnitude and polarity of this error signal is such, that when converted to d.c., amplified, and passed to the motor driver, the motor is forced to rotate at a speed at which the tachometer signal frequency exactly equals the reference frequency.

To maintain precise synchronization of the motor shaft, the computer section also contains phase-lock logic which compares the relative phase angle between the reference and tachometer signals, when frequency-lock has been achieved, and generates an error signal proportional to this phase angle. The phase error signal is used to control the motor excitation to maintain precise phase alignment between the tachometer and reference signals.

The unique feature of this control system is that the frequency-lock and phase-lock logic circuits operate simultaneously, and the transition from the frequency control mode to the phase control mode is performed automatically in a continuous manner, so that no switching signals or transients appear in the error signal.

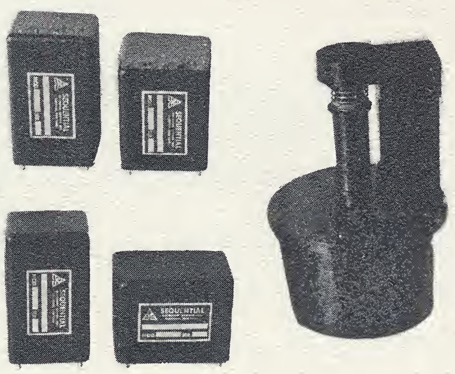
The phase error information produced by the computer is in the form of relative pulse spacing between the reference and tachometer signals. The function of the D/A converter is to convert this relative pulse spacing information into a d.c. signal proportional to the phase error. This conversion is performed on a pulse-to-pulse basis, with no significant time constant, and with virtually no ripple. The electrical bandwidth achieved is one-half the frequency of the reference signal, which permits design of an extremely wide-band and high gain control loop.

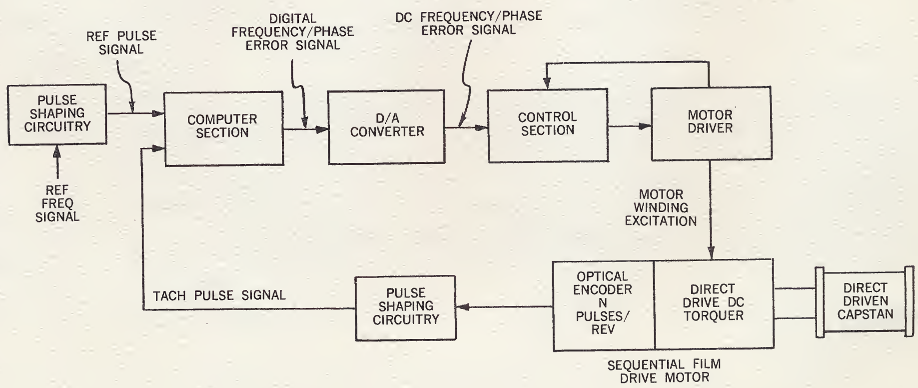
The Control Section contains stabilization circuitry which applies phase, velocity, and acceleration control in the proper ratio, and with proper frequency characteristics, to optimize the closed loop performance of the control loop. This section also contains circuitry associated with the Motor Driver. The driver unit supplies the correct excitation to the motor windings to maintain constant shaft velocity. Excitation signals from the Driver are fed to the Control Section, so that the driver and motor windings are operated in a secondary, closed-loop manner. The effect of this type of operation is to linearize the torque output characteristic, and to virtually eliminate the electrical time constant of the motor windings.

If a torque disturbance is applied to the capstan, the phase angle between the tachometer and reference signals will shift, changing the phase error signal. The torque output of the motor will change by an amount which will just cancel the torque disturbance and maintain speed synchronization. In closed loop operation, the maximum electrical phase shift is limited to $360/K_p$ degrees, where K_p is the electrical phase-lock gain. Since the tachometer produces N pulses per revolution, $360/K_p$ electrical degrees corresponds to $360/NK_p$ mechanical degrees. The mechanical phase locking that can be achieved is therefore a function of the tachometer pulse density (N), and the electrical phase-lock gain (K_p).

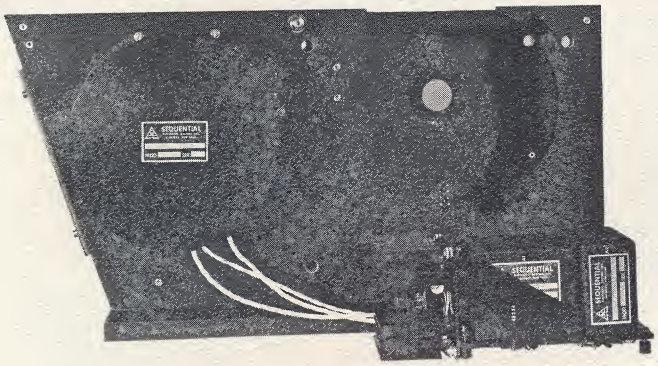
Values of achievable K_p's, with the proper dynamic stabilization are in the range of 20-40 db. These electrical gains coupled with the extremely high sensitivity of the optical tachometer determine open-loop gains on the order of 1,000,000 (120 db) radian/second/radian throughout the control bandwidth. This gain produces closed loop positional accuracies on the order of seconds of arc.

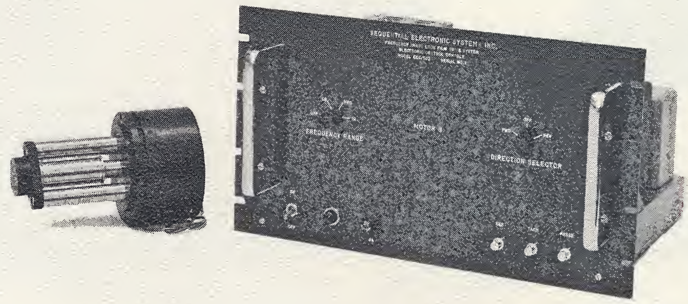
*Patent Pending





CTRONIC SYSTEMS





BAND-SCAN FPL CONTROL SYSTEM* The Band-Scan FPL Control System is the ultimate in precision motor control. It retains all the advantages of the FPL System in terms of simplicity of implementation and sophistication of control, but completely eliminates all inherently limiting characteristics (relating to control bandwidth and operational range) of sampled-data phase locking systems that derive feedback information from a pulse-rate tachometer.

Band-Scan utilizes miniaturized BAND-SCAN FPL** control electronics, a miniaturized BAND-SCAN REFERENCE GENERATOR, and an electro-optical modular BAND-SCAN READOUT*** which integrally mounts to the control motor.

OPERATION The infinite resolution Band-Scan Readout has the unique capability of electro-optically monitoring continuous speed/phase coordinates and converting this information into the required digitized format at a constant conversation rate which is independent of shaft speed. It computes speed with zero error and position or phase with a maximum peak inaccuracy of 0.33 arc seconds, at a minimum settable conversion rate of 30 kilocycles. This action produces a rate/position control system with the capability of constant closed-loop control bandwidth of a minimum of 3Kc (3 db point) which functions from true zero speed through saturation speed of the control motor.

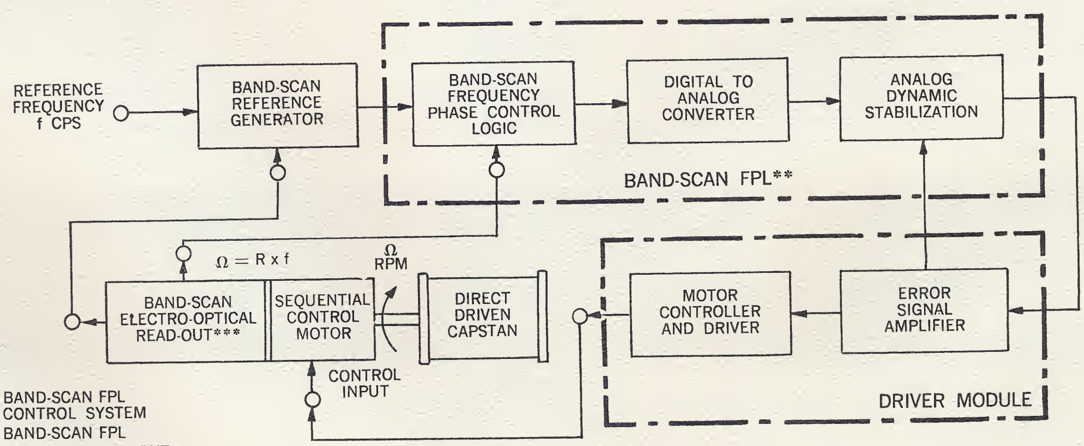
Position sensitivities are such that if the electronic gain were unity, 20 arc seconds of position error would correspond to a full applied torque command. Achievable electronic gains with the proper stabilizing elements are on the order of 40-60 db. This therefore produces total open-loop gains of 10,000,000 (140 db) radians/sec/radian throughout the control bandwidth; forcing an absolute closed-loop position control accuracy, independent of torque loading, of better than 0.5 arc seconds.

The practical aspects of such gain-bandwidth capabilities are that the effects of undesirable torque perturbations, arising either internal to the control motor, or externally applied by the load mechanism, are reduced by a minimum of 140 db within the spectral band of 0 to a minimum of 3kc. This allows the utilization of standard d.c. commutating-ball bearing torque motors for a degree of super-precision that up to now has been considered impossible to achieve. The Band-Scan FPL System can mechanize any type of a.c. or d.c., ball bearing or air bearing rotary drive. With this system the need for expensive precision air-bearings is almost entirely eliminated. A possible exception would come only in the most stringent mechanical requirements where drive shaft runout must be held to less than 25 micro-inches TIR.

Reference inputs to the Band-Scan Reference Generator are set by a pulse train whose frequency directly corresponds to commanded motor speed and whose phase relates to drive shaft position. The standard speed-frequency conversion ratio is such that motor rpm = R x f where R equals the conversion ratio selected for a given application and f = reference frequency. The reference generator samples and stores speed/phase command information. Updating of the coordinates in storage is once/cycle of the reference. The interrogation rate of the generator for information fed into the Band-Scan FPL is automatically made compatible with the conversion rate of the Band-Scan Readout.

For motor back-to-back speed/phase control, the generator is not required and the Band-Scan Readout on the master motor functions as the command for the slave motor.

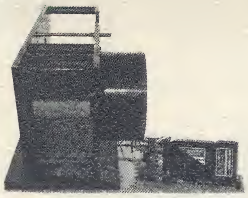
Natural binary coded or decimal rate and position information is directly available from the Band-Scan FPL for external readout on a counter.



*Patent Pending — BAND-SCAN FPL CONTROL SYSTEM
**Patent Pending — BAND-SCAN FPL
***Patent Pending — BAND-SCAN READOUT

SEQUENTIAL FILM DRIVE SYSTEMS

Film Drive Motor



	FILM DRIVE MOTOR SERIES 500	FILM DRIVE MOTOR SERIES 800
Rated Torque	90 oz-in (at 25°C)	900 oz-in (at 25°C)
Sensitivity (Nominal)	48 oz-in/amp	192 oz-in/amp
Operating Speeds		
FPL System	3-300 RPM	2-225 RPM
Band Scan System	0-300 RPM	0-225 RPM
Dynamic Speed Range	Specified by Customer	Specified by Customer
Maximum Tachometer Pulse Density	32,400 pulses/rev.	64,800 pulses/rev.
Capstan Runout (TIR)	.0001 in.	.0001 in.
Size (less capstan and mtg. plate)		
Diameter	5. in.	8. in.
Length	4 5/16 in.	4 3/4 in.
Direction of Rotation	All motors are capable of running in either the CW or CCW direction	

Note: Motors to meet military specification requiring explosion proofing are available.

SPECIFICATIONS

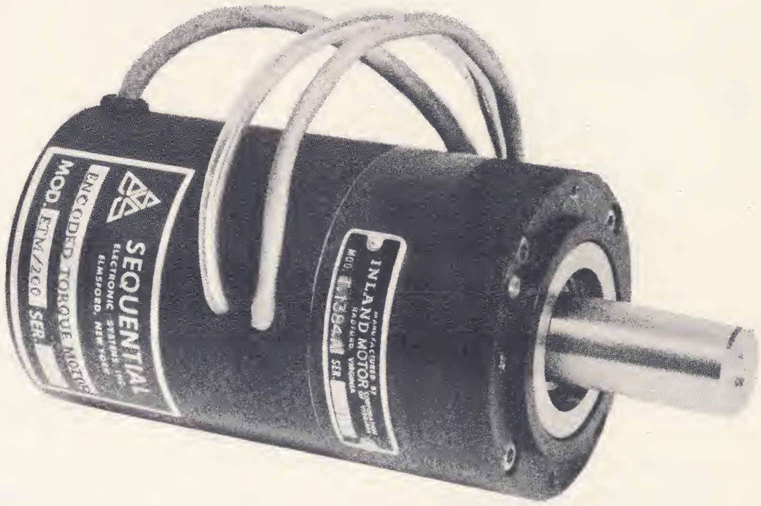
		SERIES 500 MOTOR	SERIES 800 MOTOR
Electronic Control Console	Reference Signal Input		
	Frequency		
	FPL System	$f = \frac{\Omega N}{60}$	$f = \frac{\Omega N}{60}$
	Band Scan System	$f = \frac{\Omega}{R}$	$f = \frac{\Omega}{R}$
	Amplitude	Sinewave: 5.0 V RMS, or Squarewave: 4.0 V peak, or Pulse 4.0 V peak, 10 microsec min. width	Sinewave: 5.0 V RMS, or Squarewave: 4.0 V peak, or Pulse 4.0 V peak, 10 microsec min. width
	Source Impedance	2000 ohms max., zero DC level	2000 ohms max., zero DC level
	Power Requirements	115 volts, 60 cps or 400 cps, single phase	115 volts, 60 cps or 400 cps, single phase
	Size		
	Electronic Control Console	19″ W x 10½″ H x 12″ D	19″ W x 10½″ H x 12″ D
	Motor Power Supply	Included in Electronic Control Console	19″ W x 7″ H x 16″ D
Electronic Control Assembly	Reference Signal Input		
	Frequency		
	FPL System	$f = \frac{\Omega N}{60}$	$f = \frac{\Omega N}{60}$
	Band Scan System	$f = \frac{\Omega}{R}$	$f = \frac{\Omega}{R}$
	Amplitude	Sinewave: 5.0 V RMS, or Squarewave: 4.0 V peak, or Pulse 4.0 V peak, 10 microsec min. width	Sinewave: 5.0 V RMS, or Squarewave: 4.0 V peak, or Pulse 4.0 V peak, 10 microsec min. width
	Source Impedance	2000 ohms max., zero DC level	2000 ohms max., zero DC level
	Input Power		
	Lamp Power		
	Voltage	5±0.25 V DC	5±0.25 V DC
	Current	225 MA	225 MA
	Regulation	0.5%	0.5%
	Ripple	5 MV	5 MV
	System Power		
	Voltage	plus and minus 12±1 V DC	plus and minus 12±1 V DC
	Current		
	Plus	700 MA	700 MA
	Minus	350 MA	350 MA
	Regulation	.05%	.05 %
	Ripple	1 MV	1 MV
	Motor Power		
	Voltage	28 V DC	Based on specific application
	Current	2 amp. current limiting	Based on specific application
	Regulation	0.5%	0.5%
	Ripple	5 MV	5 MV
	Size (less Band Scan Ref. Gen.)	9½″ L x 3″ W x 5½″ H	9½″ L x 3″ W x 5½″ H
System	Position Control Accuracy (Instant. Pos. Perturbations)		
	FPL System	±1 second of arc	±1 second of arc
	Band Scan System	±0.5 seconds of arc	±0.5 seconds of arc
	Speed Accuracy	100% motor speed accuracy with respect to the reference frequency (zero cumulative error in motor speed). Absolute accuracy is equal to the accuracy of the ref. freq.	
	Flutter Reduction		
	FPL System	100-120 db	100-120 db
	Band Scan System	140 db min.	140 db min.
	3 db Control Bandwidth		
	FPL System	20% of reference freq. max.	20% of reference freq. max.
	Band Scan System	Fixed at 3KC min.	Fixed at 3KC min.

Note: Specifications apply to both the Sequential FPL System and the Sequential Band Scan System, unless otherwise indicated.

SEQUENTIAL ELECTRONIC SYSTEMS, INC.
66 Saw Mill River Road, Elmsford, New York (914) LYric 2-8810 TWX 914 592 8368

SEQUENTIAL ELECTRONIC SYSTEMS

ENCODED D.C. TORQUE MOTOR



FEATURES:

A single package optically encoded d.c. tape drive torquer

Integral capstan assembly

Easy access to brushes in installed unit

Extremely high density and accuracy of optical encoders

Fast torquer response time

Low ripple torque

Ultra-high torque to Inertia ratio

Encoder configurations for all tape recording applications

100 micro-inch max capstan runout

SERIES 200

APPLICATIONS:

Instrumentation, analog, and FM recording employing a tachometer optical encoder

Incremental and punched tape readers employing incremental optical encoders

Video recorders employing tachometer optical encoder plus absolute indexing

The Sequential Encoded Torque Motor, Series 200, integrates a high speed d. c. torque motor with a Sequential Optical Encoder in a single package. The Series 200 is utilized for precise direct drive and incremental positioning mechanisms in a wide variety of tape recorders and readers.

The Optical Encoder is directly assembled to the torquer shaft and provides required readout information for the closed loop control and external monitoring of speed/position coordinates. The Optical Encoder mechanization is a function of the type of recorder utilizing the package. It is instrumented as a tachometer readout for application in instrumentation, analog, and FM recorders. For incremental recorders and punched tape reader applications, the Optical Encoder provides an incremental positional readout. In video recording applications, the Optical Encoder includes both tachometer and absolute indexing readouts.

The unique Sequential d.c. torquer was specifically designed for these recording applications in conjunction with Inland Motor Corp. Inland manufactures these motors for Sequential under an exclusive sales-manufacturing agreement. Performance characteristics and production electromechanical tolerances are far superior to any other type of drive.

Direct drive torquers insure high load coupling "stiffness" with consequent high mechanical resonant frequency offering the design capability of an extremely wide servo bandwidth. The d.c. fields generate maximum available torque at stall and coupled with the low armature inertia results in minimum acceleration and deceleration to commanded speed and position.

In addition to these generally accepted advantages of d.c. torquers, Inland's manufacturing and engineering insures a widely recognized high quality production and general product excellence.

The Sequential Optical Disc is a basic component of the Sequential Optical Encoder. The Optical Disc is directly mounted to the end of the torquer shaft opposite to the capstan. The Optical Disc is a photographically reproduced copy of a master disc that has been calibrated to a total inaccuracy of less than 0.2 arc-seconds from one arbitrary section to any other arbitrary section around a revolution. The master disc was processed on the proprietary Sequential Automatic Circle Dividing Machine, the most accurate circle dividing machine in existence.

Available disc densities in the Series 200 are the highest ever obtained, and extend well into the light diffraction region. Sequential Electro-Optical Readouts are designed to account for resultant diffraction effects.

Readout errors of a greater magnitude than 0.2 arc-seconds are evidenced because of non-perfect concentric mounting of the Optical Disc. However, the Disc tracks are optically centered so that the worst possible once/revolution (first harmonic) positional inaccuracy is held to less than ± 7 arc-seconds, as referenced to a perfect capstan. This compares favorably with the most stringent requirements of mechanical runout (TIR) on precision capstans. For example, a 50 micro-inch TIR on a one inch diameter capstan is equivalent to ± 10 arc-seconds of first harmonic. For more critical applications, a multi-station electro-optically phased readout technique is employed which reduces the total readout inaccuracy to less than ± 1.0 arc-second.

Wide-angle optical readout, averaging over several hundred opaque-clear line pairs, minimizes high frequency outputs due to glass surface irregularities of the track.

The excitation light from the incandescent bulb is optically shaped to decouple filament vibrations and to make spatial orientation of the filament an unimportant parameter.

For the normal encoder implementation (as a non-diffraction region tachometer), the collimated excitation light is focused through the appropriate sector of the disc on the "window" of a wide-band silicon photo diode. Signal readings are effected through the medium of a stationary interrogation grating placed between the interrupted excitation light beam and the photo diode "window".

All electro-optical readout amplifiers are contained within the housing. These amplifiers are either instrumented as tachometer sensors (i.e.; for positive readout motor shaft must be turning above a minimum speed of 1 rpm), or as a true d.c. positional readout (Patent Pending) with positive ultra-stable outputs from zero to saturation speed of the torquer. The positional readout output is a d.c. voltage which is a sinusoidal function of incremental position; for an N line disc (N opaque and clear sections/rev.) there are N sinusoids/revolution of the torquer shaft, and the d.c. average voltage of each sinusoid is a true zero level.

True positional readout and mechanization of the series 200 as a drive unit for an incremental recorder allows ultra-high bit densities at least one order of magnitude higher than existing systems. Direction sensing and absolute indexing are available.

For the Series 200 motor, Sequential manufactures control systems for both speed/phase and incremental recording applications.

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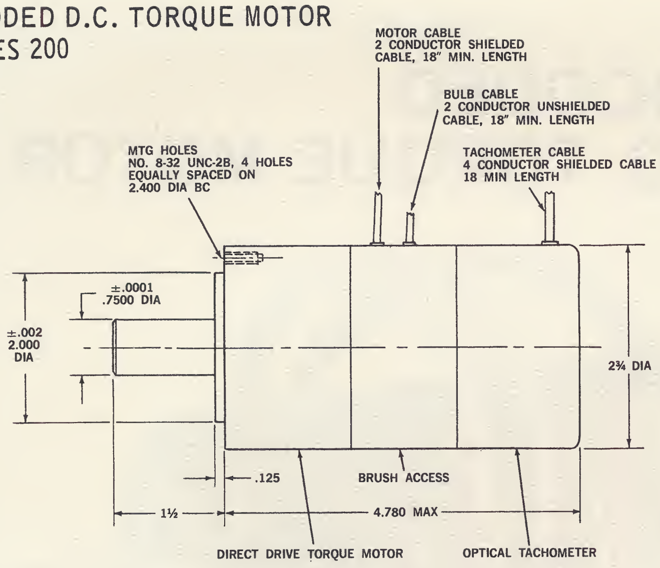
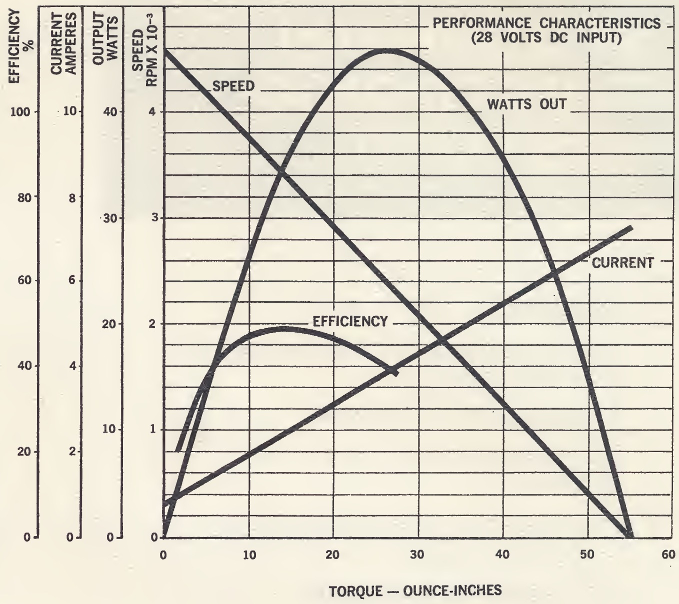
ENCODED D.C. TORQUE MOTOR
SERIES 200



OUTLINE DRAWING



TORQUER CHARACTERISTICS

Rated Speed (continuous duty)	3300 rpm
Rated Torque (continuous duty, for 70°C Rise)	15 oz-in
Peak Torque Developed @ Air Gap	60 oz-in
Output Stall Torque	55 oz-in
Rated Voltage	28 vdc
Rated Current (continuous duty, for 70°C Rise)	2.6 amps
Peak Allowable current	13 amps
Power Output at 3300 RPM	37 watts
Torque Gradient (developed @ air gap)	7.0 oz-in/amp
Back EMF	.0052V/rpm
Armature Resistance (at 25°C)	2.60 ohms
Electrical Time Constant	.0003 sec
Maximum permissible winding temperature	155°C
Inertia (Motor and Encoder)	.0067 oz-in-sec²
Viscous Damping (zero impedance source)	.014 oz-in/rpm
Viscous Damping (infinite impedance source)	.0009 oz-in/rpm
Mechanical Time Constant (zero impedance source) (on start-motor and encoder)	.050 sec
Ripple Torque	less than 3% of output torque level
Maximum Friction Torque	3.5 oz-in
Maximum Theoretical Acceleration (Motor and Encoder)	8200 rad/sec²
Brush Life (@ rated load and speed)	1000 hours
Bearings (both ends)	Sealed duplex
Magnetic Field	6 Pole Alnico
Number of commutation segments	31
Number of Brushes	2 pair
Weight	3 pounds

Note:
1. Special shaft configurations are available.

ENCODER CHARACTERISTICS

Optical Disc Density	up to 10,000 pulses/rev available
Optical Disc Accuracy	0.2 Arc seconds from one line to any other arbitrary line around a revolution
Output Tachometer signal	saturated sinewave, 10±2V p-p
Output Signal Accuracy, with electro-optical disc eccentricity cancellation	±1.0 arc-second
Output error due to eccentric mounting of disc (first harmonic)	±7.0 arc seconds standard
Output Impedance	less than 5 K ohms
Output Frequency (F=WN/60, W=RPM, N=Tachometer Pulse Density)	Up to 1.0 mc available
Lamp Life	20,000 hours min.
Input Power	
Lamp Power	
Voltage	5.6 vdc
Current	
without eccentricity cancellation	200 ma
with eccentricity cancellation	400 ma
Regulation	1%
Ripple	5 mv
Amplifier Power	
Voltage	±12 vdc
Current	
+12 vdc	60 ma
−12 vdc	50 ma
Regulation	1%
Ripple	5 mv

Notes:
1. Available with direction sensing and/or zero index.
2. Encoders to operate with other power supply voltages available.

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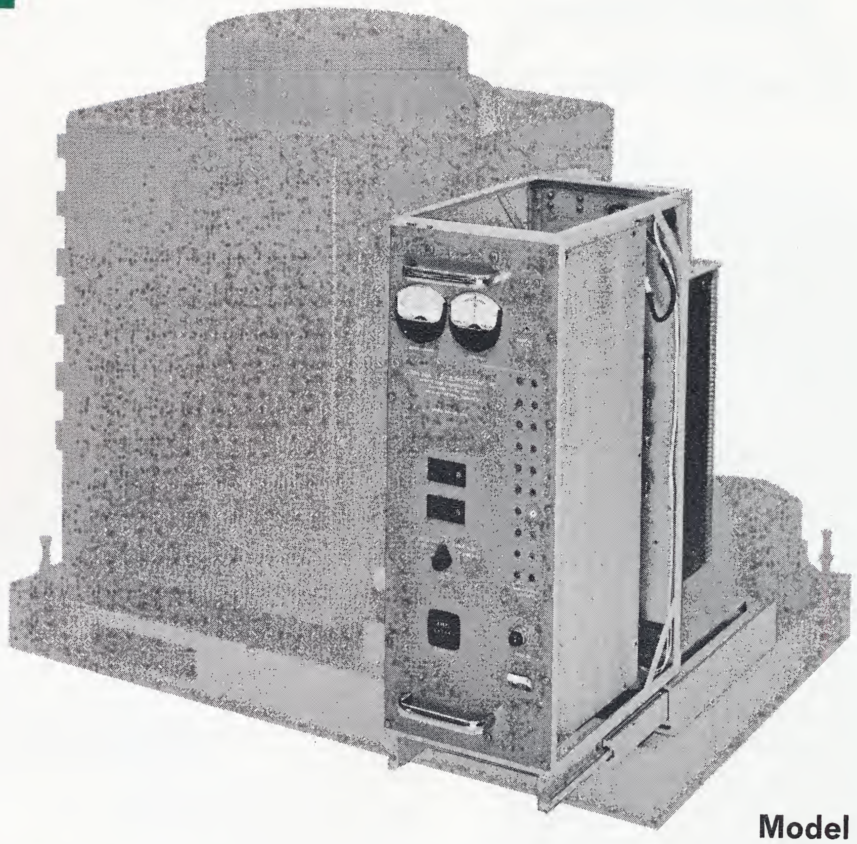
SEQUENTIAL ELECTRONIC SYSTEMS

MAGNETIC DRUM SYNCHRONIZATION SYSTEM



Model DS12

FEATURES

- Time displacement error less than 100 ns
- Unlimited number of drums can be electronically geared to perform as a single unit
- Non-volatile storage
- Absolute position control of all drums under all conditions i.e. even after power failure
- No trim adjustments
- Increases storage capacity of alpha-numeric display systems or digital computers on a modular basis
- Integrated circuit electronic assemblies available for airborne applications
- Projected electronics MTBF greater than 15,000 hours
- Meets all applicable MIL-SPECS

INTRODUCTION

The Sequential Magnetic Drum Synchronization System Model DS12 electronically gears any number of individual drums with a time displacement error (TDE) of less than 0.2 microseconds between any two arbitrary drums. Prior state-of-the-art required that a reference track on a single drum determine the clock rate of a digital computer or display system. Lack of precision drum synchronism, thereby restricted a computer or display to limited storage access obtainable by a single drum.

The technique employed by Sequential couples individual drums by means of an external reference frequency. This reference is utilized as the clock frequency for the computer or display system. Therefore, a flexible modular approach to present memory storage problems is now available. The storage capacity of a system can be increased, without limit, by the addition of any number of controlled drums.

OPERATION

The Sequential Drum Synchronization System Model DS12 may be described in terms of four (4) interacting control functions. These functions are:

a) The primary speed/phase control as implemented by an FPL SPEED/PHASE CONTROL LOOP.
b) A phase correction control as implemented by the PHASE CORRECTION LOOP.
c) A reference generator control as implemented by the REFERENCE GENERATOR LOOP.
d) An indexing control as implemented by the INDEXING LOOP.

Figure 2 is the System Block Diagram. This figure indicates the four (4) broad functional control loops. Figure 3 presents a functional block diagram of the system. In this block diagram each of the major blocks of Figure 1 have been broken down into several functional components.

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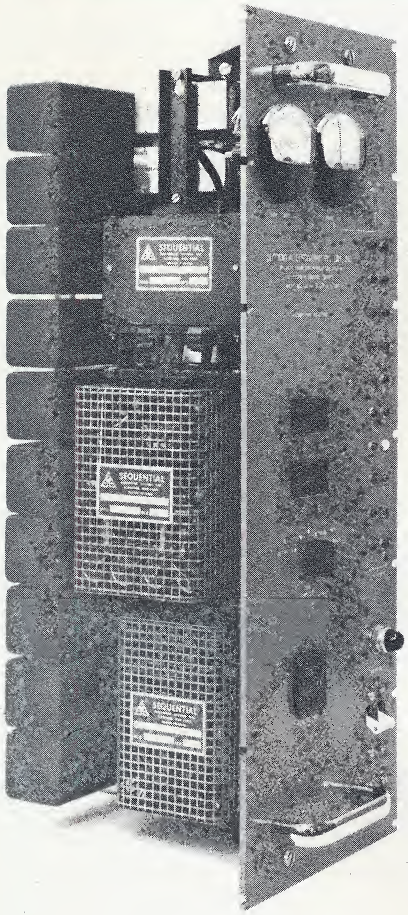


INPUT SIGNAL FUNCTIONS

A. *Reference Clock Signal*

The Reference Clock Signal is a timing pulse train whose leading edge generates incremental position commands to the drum, and whose frequency generates precise speed commands. The drum speed is directly proportional to the Reference Clock Signal frequency. If the Reference Clock Signal frequency is lowered, the drum will decrease in speed. If the Reference Clock signal frequency is increased, the drum will increase in speed.

B. *Reference Index Signal*

The Reference Index Signal is a command index pulse whose leading edge is aligned with a leading edge of one of the Reference Clock Signal pulses. The Index Signal repeats once per drum revolution. If the Reference Index Signal is removed, after the drum has achieved index synchronism, the drum will maintain index synchronism unless a disturbance occurs to shift the drum position by more than one bit spacing within the index slot.

C. *Drum Clock Signal*

The Drum Clock Signal is the high frequency (N pulses/rev) feedback control signal and is electromagnetically derived from a track on the drum.

D. *Drum Index Signal*

The Drum Index Signal is the once/rev feedback control signal and is electromagnetically derived from a track on the drum. This Index pulse is centrally located between two Drum Clock Signal pulses.

DUAL READ AMPLIFIER

The Dual Read Amplifier is used to shape and amplify the Drum Clock signal and the Drum Index signal. Figure 3 shows the input and output characteristics of the Dual Read Amplifier.

FPL SPEED/PHASE CONTROL LOOP

The Speed/Phase Control Loop utilizes as it inputs a reference pulse train that is generated by the Reference Generator Loop and the Phase Correction Loop, and a feedback pulse train that is derived from the Dual Read Amplifier.

This speed/phase loop locks the drum clock frequency to the incremental reference. The incremental reference and the drum clock signals are compared on a frequency/phase basis in the FPL* Computer Module which generates an error signal accordingly. The magnitude and polarity of the frequency error is such, that when converted to d.c., amplified, and passed to the brake driver, the drum is forced to rotate at a speed at which the clock pulse frequency equals the reference frequency.

To maintain precise synchronization, a phase error signal is generated once the drum has achieved synchronism. The phase error signal controls the brake excitation to maintain "tight" phase alignment between the reference pulse train and the feedback signal, when frequency-lock has been achieved.

The unique feature of the FPL Computer is that the frequency lock and phase lock logic operate simultaneously, and the transition from the frequency control mode to the phase control mode is automatically performed in a continuous manner, so that no switching signals or transients appear in the error signal.

The phase error information produced by the computer is in the form of relative pulse spacing between the reference and tachometer signals.

The function of the D/A CONVERTER MODULE is to convert the above relative pulse spacing (phase error) information into a d.c. signal proportional to the phase error. This conversion is performed on a pulse-to-pulse basis, with no significant time constant, and with virtually no ripple. The electrical bandwidth is one-half the frequency of the reference signal, which permits design of an extremely wideband and high gain control loop.

The STABILIZATION MODULE contains circuitry which applies phase, velocity, and acceleration control in the proper ratio, and with proper frequency characteristics, so as to optimize the closed loop performance of the control loop. This module also contains circuitry associated with the Brake Driver Assembly.

The BRAKE DRIVER ASSEMBLY supplies correct excitation to the Brake windings to maintain precise drum synchronism. Excitation signals from the Driver are fed back to the Stabilization Module, so that the driver and brake windings are operated in a secondary closed loop manner. The effect of this type of operation is to linearize the torque output characteristics, and to virtually eliminate the electrical inductive time constant of the brake windings.

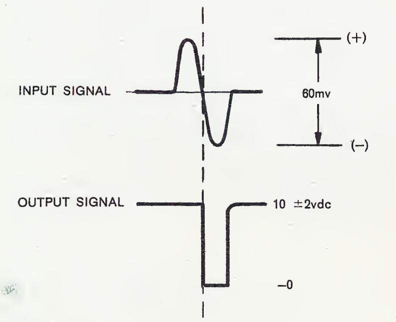


Figure 1 – Dual Read Amplifier Signal Characteristics

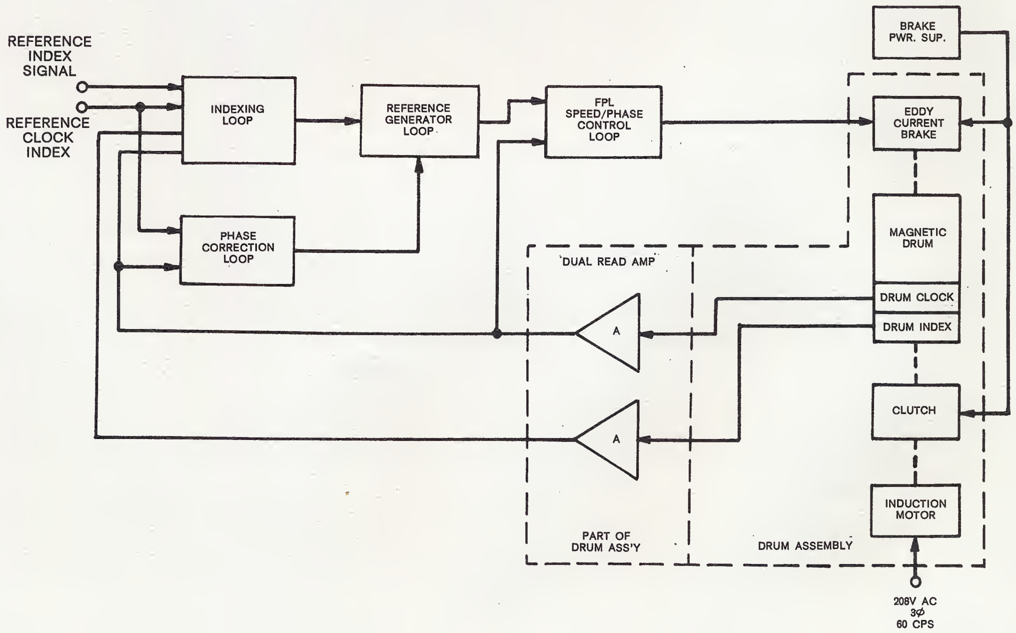


Figure 2 – System Block Diagram: Sequential MDSS* Control and Indexing System Model No. DS12

If a torque disturbance is applied to the drum the phase angle between the reference and feedback signals will shift changing the phase error signal. The torque output of the brake will change by an amount which will just cancel the torque disturbance and maintain speed synchronization. In closed loop operation, the maximum electrical phase shift is limited to 360/Kp degrees, where Kp is the electrical phase-lock gain. Since the drum clock produces N pulses/revolution, 360/Kp electrical degrees corresponds to 360/NKp mechanical degrees. The mechanical incremental phase locking of the drum is therefore a function of the Drum Clock pulse density (N), and the electrical phase-lock gain (Kp).

As in any mechanical structure, there will be certain torsional structural resonances of the mechanical load; therefore necessary bandwidth cutoff filters are incorporated within the stabilization module. These cutoff filters insure that loop gains at and beyond resonance frequencies are sufficiently attenuated so as to not reinforce or trigger structural resonances.

The control loop is a hybrid type of instrumentation with digital error sensing and analog stabilization parameters. This mechanization fulfills the necessary conditions of both high accuracy and superior dynamic performance.

REFERENCE GENERATOR LOOP

The Reference Generator Loop may be considered as a function generator, which receives either of the following signals:

a) The true Reference Clock signal if the Index Slot is at the proper index position with respect to the Reference Index.

b) A Positive Shift Reference Signal proportional to the phase lag of the Index Slot relative to the Reference Index.

c) A Negative Shift Reference Signal proportional to the phase lead of the Index Slot relative to the Reference Index.

To maintain a constant but adjustable phase relationship between the Reference Clock Signal and the Drum Clock Signal a d.c. control voltage, derived from the Phase Correction Loop is also fed into the Reference Generator Loop. This phase correction is achieved by shifting the leading edge of the Phase Shift Module output signal in the proper direction so as to correct for any steady state disturbance in the drum position.

Three (3) modules make up this loop; the Frequency Shift Module, the Frequency Comparator Module, and the Phase Shift Module.

PHASE CORRECTION LOOP

The Phase Correction Loop utilizes as it inputs the Reference Clock Signal and the feedback pulse train or Drum Clock Signal as seen at the output of the Dual Read Amplifier.

The Phase Comparator Module generates a signal whose phase angle is equivalent to the phase error between the Reference Clock Signal and the Drum Clock Signal on a pulse-to-pulse basis.

The Phase Integrator receives a phase error signal from the Phase Comparator Module and converts it to a d.c. signal proportional to phase error. This d.c. signal phase shifts the output of the Reference Generator Loop to force the phase error to a null.

The Phase Null is set at 180 degrees phase shift between the Reference Clock Signal and the Drum Clock Signal.

The Phase Null point may be adjusted with the Phase Null Adjust provided on the instrument panel and may be observed on the Phase Null indicator also provided on the instrument panel. The Phase Null Indicator reads a null for a 180 degree phase shift.

INDEXING LOOP

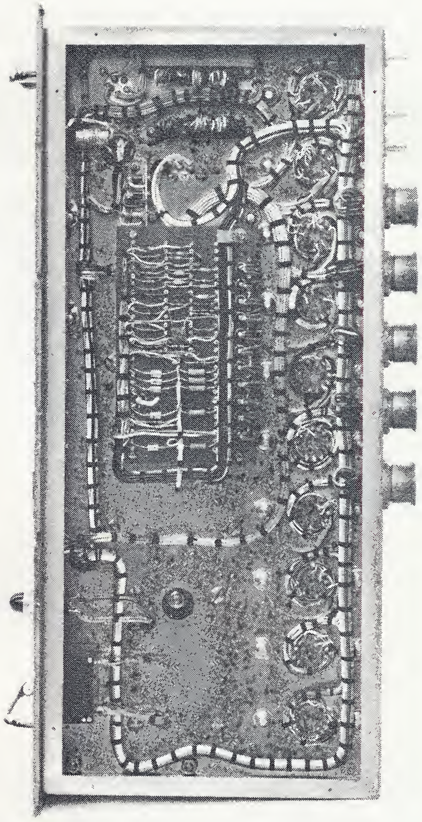
The Indexing Loop utilizes as its primary inputs the Reference Clock Signal, Reference Index Signal, Drum Clock Signal, and the Drum Index Signal.

The Drum Clock and Drum Index signals are derived from the Dual Read Amplifier.

The Index Gating Module tags a particular index slot which is between the seventh and eighth bit on the Drum Clock Signal with respect to the Reference Index Signal. The index slot is generated from the start of a Drum Index Signal. The actual Drum Index position is at 180 degrees between the seventh and eighth bit on the Drum Clock Signal.

The Index Comparator Module senses and continuously monitors the position of the index point. The gating logic selects and gates through the proper correction signals to the Reference Generator Loop.

*Patent Pending



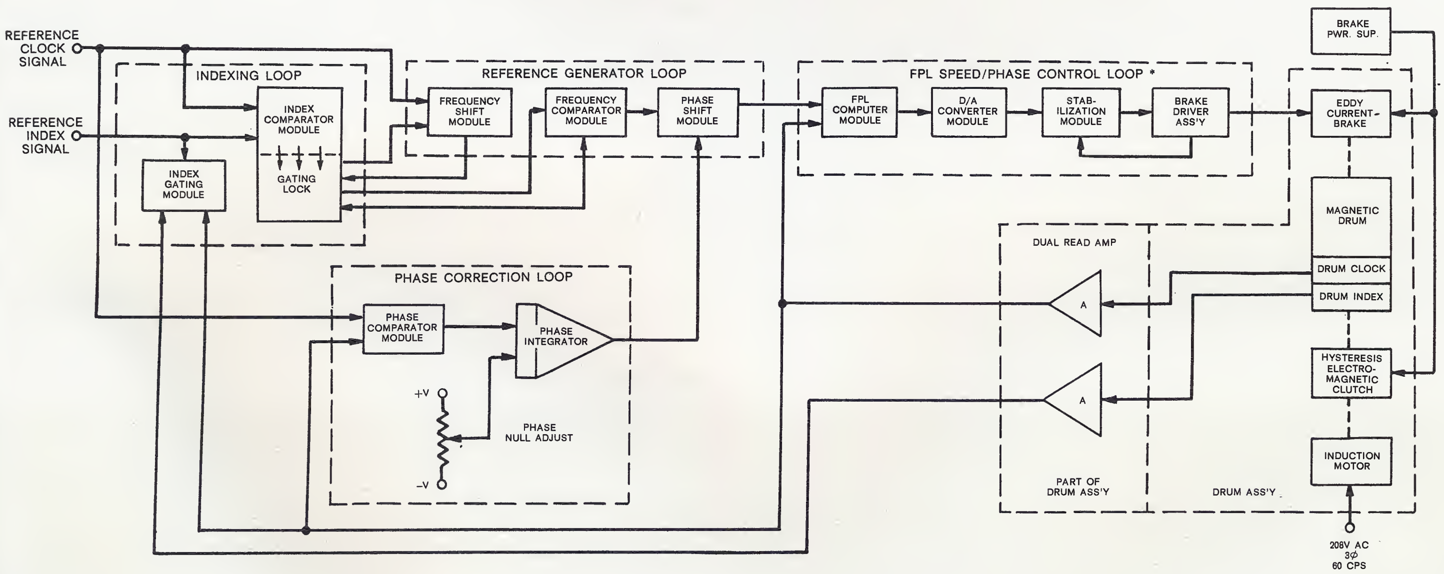
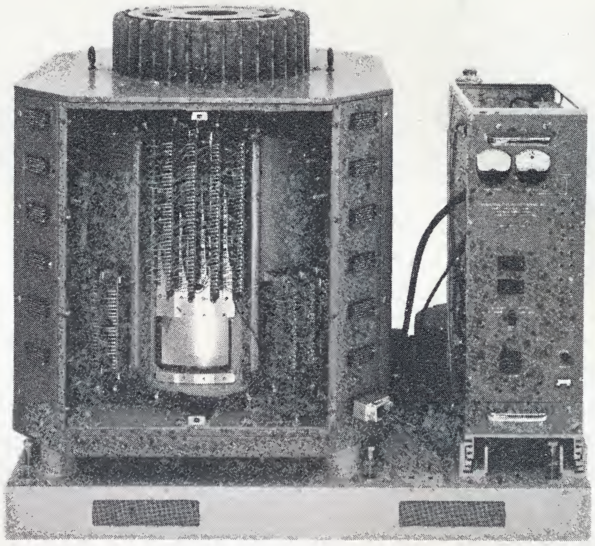


Figure 3 — Functional Block Diagram: Sequential MDSS* Control and Indexing System Model No. DS12

SEQUENTIAL MAGNETIC DRUM SYNCHRONIZATION SYSTEM

MODEL DS12



SPECIFICATIONS

Drum Speed (ΩRPM)	Specified by customer
Drum Clock Pulse Density (N)	Based on Specific application
Reference Signals	
Clock Signal	
Frequency	$f = \frac{\Omega N}{60}$ cps
Waveform	Zero Based Position Pulse
Amplitude	2 volts
Base line noise	±0.15 volts max
Duty Cycle	less than 50%
Rise Time	0.15 microseconds max
Source Impedance	600 ohms max
Index Signal	
Frequency	$f = \frac{\Omega}{60}$ cps
Waveform	Zero based positive pulse
Amplitude	2 volts
Base line noise	±0.15 volts max
Duty cycle	less than 50%
Rise time	0.15 microseconds max
Source Impedance	600 ohms max
Phase Alignment	Reference Index Pulse must be phase locked (counted down from the clock signal) to the clock signal and aligned with a clock pulse within ±0.5 microseconds
Drum Signals	
Clock Signal	
Frequency	$f = \frac{\Omega N}{60}$ cps
Waveform	essentially sinusoidal pulse
Amplitude	60 mv p-p min
Signal Source	Magnetic Head
Signal-to-Noise Ratio	12 db min

Index Signal	
Frequency	$f = \frac{\Omega}{60}$ cps
Waveform	essentially sinusoidal pulse
Amplitude	60 mv p-p min
Signal Source	Magnetic Head
Signal-to-Noise ratio	12 db min
Phase Alignment	Drum Index Pulse to be located approximately 180 degrees between two clock pulses
Absolute Position Accuracy (Time Displacement Error, TDE)	±0.1 microseconds non cumulative
Input Power	
Voltage	115 volts single phase or 208 volts 3 phase
Frequency	60 cps or 400 cps
Current	Based on specific application
Size	
Electronic Control Console (1)	9″ w x 24″ h x 11″ d
Brake Power Supply	Based on specific application
Dual Read Amplifier	3″ w x 3″ h x ¾″ d
Temperature Range	
Operating	0°C to +60°C
Non-operating	−55°C to +71°C
Humidity	97%
Vibration	.005 inches double amplitude from 10 to 55 cps; .005 inches double amplitude from 55-500 cps with a maximum acceleration of 5 g's
Shock	5 g's in any plane, 11 milliseconds duration

Note
1. Miniaturized integrated circuit electronic assembly available

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Bulletin MDS
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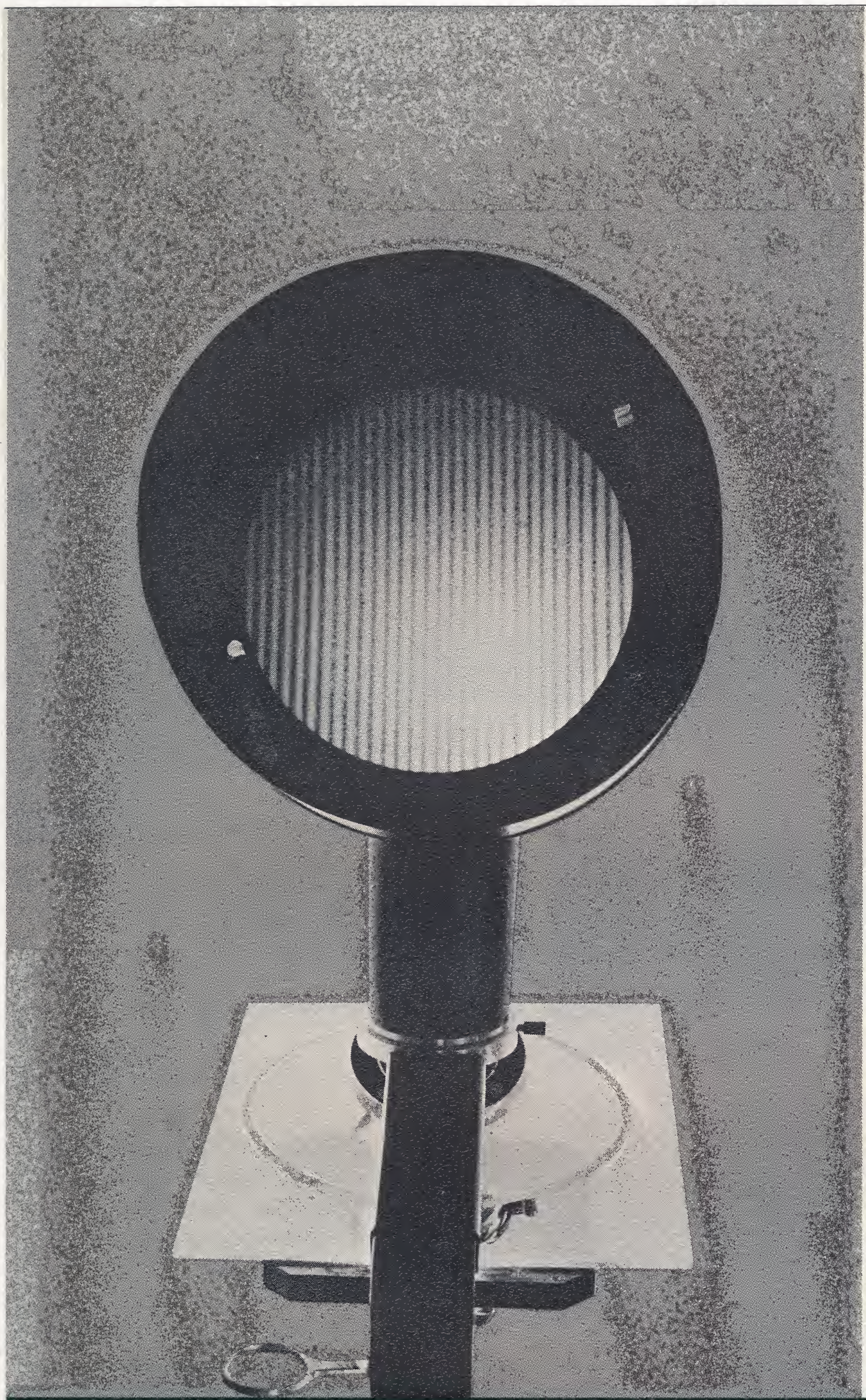

SEQUENTIAL

PRECISION
OPTICAL
CODED DISCS

ENCODERS

OPTICAL
RESOLVERS

MEASURING
SYSTEMS

SEQUENTIAL ELECTRONIC SYSTEMS, INC.
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Photographic processing of coded disc plates

Inspecton of coded disc track

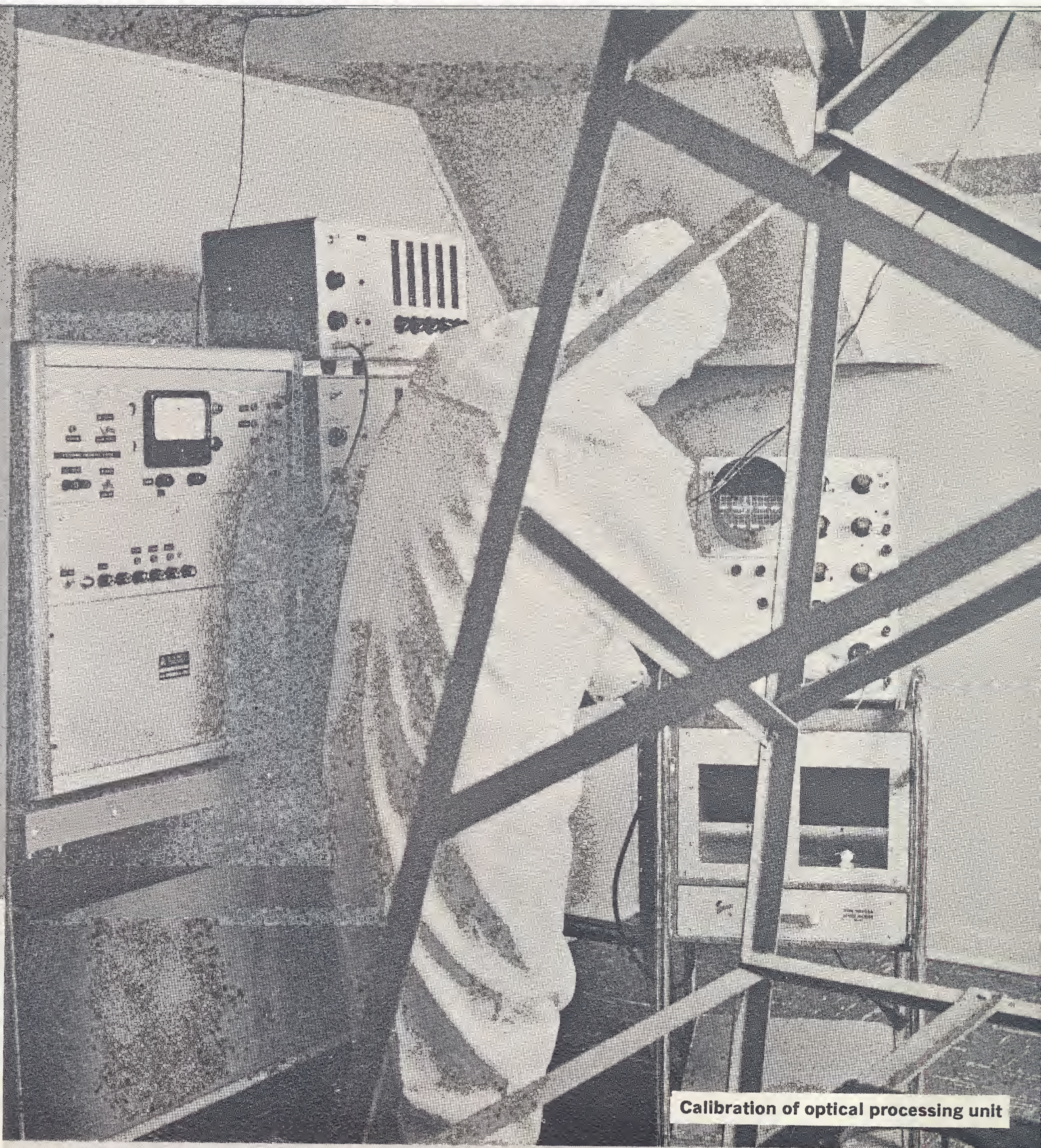
Precision grinding of disc diameters

SEQUENTIAL PRECISION OPTICAL PROCESSING FACILITIES

The urgent requirements for consistently uniform and extremely precise optical encoder discs led to the establishment of optical processing and production facilities at Sequential Electronic Systems, Inc. These facilities, and the electronic, electro-optical, and mechanical hardware capabilities of Sequential are available to produce precision optical coded-discs, complete encoder packages, and electro-optical measuring systems.

The heart of the optical processing facility is the Sequential designed and produced Automatic Circle Dividing Machine, the most accurate machine of its type presently available. The proven capabilities of this equipment are the production of master coded-discs with accuracies of 0.2 arc seconds and densities of over 5000 opaque and 5000 clear segments per inch. In addition, these master discs feature no closure or cyclic errors. A continuing program of

600X magnification of 64,000 line track (3300 lines per inch)

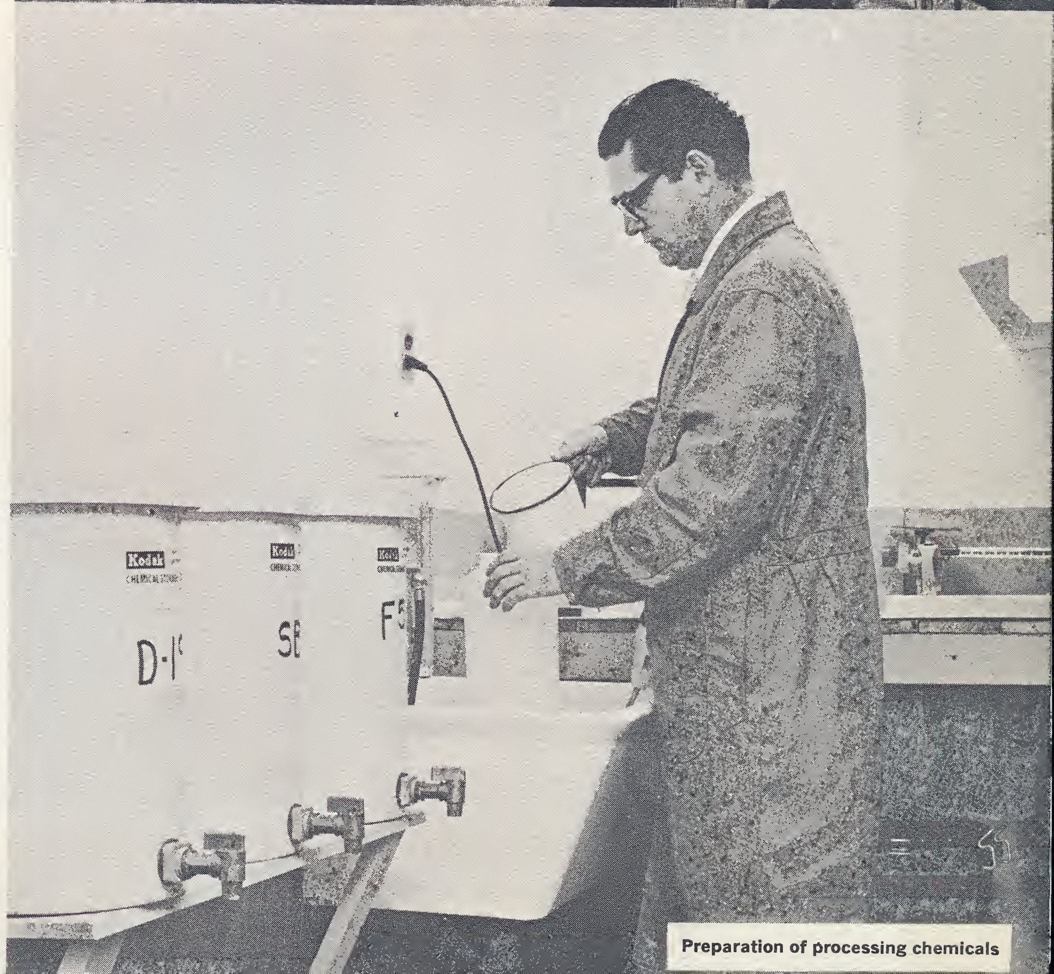


Calibration of optical processing unit

modifications and improvements is underway to increase the capabilities of this facility. Unique master copying equipment insures that all coded-discs are produced with the same basic accuracy as the master discs.

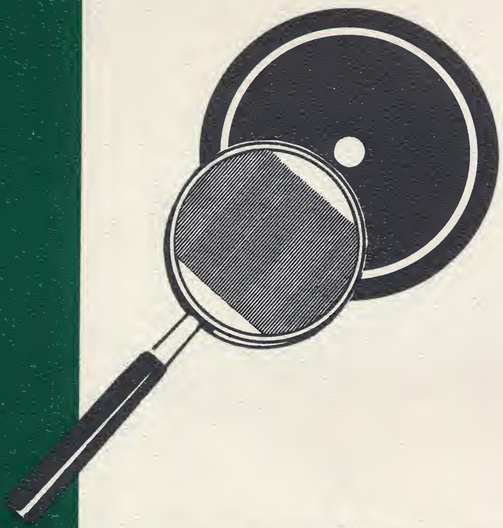
The production of all coded-discs and complete encoder assemblies is carried out in dust-free, temperature and humidity controlled areas. All water and chemicals used in the production of these discs are specially filtered and temperature controlled to maintain consistent uniformity and accuracy.

Sequential facilities and personnel are available for the production of special optical coded-discs, extreme high density encoder discs, complete encoder assemblies including all required electronics, encoded motor packages, optical resolvers and special electro-optical measuring equipment.



Preparation of processing chemicals

SEQUENTIAL PRECISION PRODUCTS



Optical disc with 64,000 clear and 64,000 opaque segments on a six (6″) diameter track. Line to line accuracy, 0.2 arc seconds.

A pancake type 2^{16} incremental encoder in a 3.4 inch diameter housing. Resolution is $\pm$10 arc seconds. All silicon electronics, and sensor readout signals of 0.5 volts are standard. Direction sensing, and zero reference are available.

Size 15 servo mount optical encoder. Resolution is 2^{14} bits. All silicon readout electronics are standard and contained in housing.

SEQUENTIAL SUPER-RESOLVERSYN*, pancake type, eight inch diameter. This electro-optical transducer provides standard resolver outputs with 64,800 poles accurate to 0.2 arc seconds. Features include infinite resolution, temperature and noise insensitivity, and all silicon electronics.

*Patent Pending

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